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LLNL Explosives Handbook

Properties of Chemical Explosives and Explosive Simulants

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FOREWORD

This handbook presents information and data for high explosives (HEs) of interest to programs at the Lawrence Livermore National Laboratory (LLNL) and other Department of Energy (DOE) facilities. It is intended to be useful to the scientist or engineer, the novice or expert, who needs to develop a new weapon system, design a physics experiment, or select and/or evaluate an existing explosive. Research explosives are excluded since most such compositions are insufficiently characterized.

This compilation is therefore limited to production HEs and their components. It is intended as a working handbook and not a historical document. The loose-leaf format is designed to permit easy revision and updating as new information and data become available. Thus, additions and corrections are welcomed by the compiler.

High explosives are divided into two classes: initial detonating (or primary) and noninitiating (or secondary) explosives. The primary HEs, such as azides and fulminates, are extremely sensitive to ignition by heat, shock, and electrical discharge; ignition leads to high-order detonation of the material--even for milligram quantities. The use of these HEs is therefore limited to squibs and starting materials for low-energy detonators. Because primary explosives have little application at LLNL, this compilation includes only the properties of lead azide and lead styphnate. Secondary HEs as a class comprise single compounds or mixtures; the mixtures contain one or more explosive compounds and one or more of the following ingredients: metals, binders, plasticizers, sensitizers or desensitizers, oxidizers, and a coloring agent. Because many of the secondary high explosives (which are formulated and manufactured within the DOE complex) are mixtures, the properties of the additives and binders used are included.

The data are the most up-to-date and accurate available to the knowledge of the compiler. Some data, however, represent only a range, an approximation, or comparative value; this is especially true of explosive mixtures, and such cases are noted in the text as they occur. The sources of information include textbooks, journal articles, technical reports, memoranda, letters, and personal communications. Data not specifically referenced were obtained from an earlier edition of this compilation*; further information and

* Properties of Chemical Explosives and Explosive Simulants, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-51319, Rev. 1 (1974).

additional references can be obtained from the compiler. References are listed at the end of each chapter. THE READER IS URGED TO CONSULT THE SOURCE DOCUMENT TO PROPERLY EVALUATE AND INTERPRET THE DATA GIVEN IN THIS COMPILATION.

The compilation consists of sections on high explosives and mock explosives, formulation nomenclature (codes), data sheets on individual materials, and a bibliography. Not all properties listed in the text and tables could be adapted to the data-sheet format, however. For the sake of uniqueness and convenience, in general only items not given as references are included in this bibliography. The references at the end of each chapter complement the bibliography; in fact they constitute specialized bibliographies.

A list of abbreviations and symbols and a table of conversion factors are given below. All values and units have been converted to the International System of Units (SI)*; throughout this handbook, SI values are given in parentheses following values in English or metric units. The units and conversion factors are also given on other tables and figures where used.

Reference to a company or product name in this compilation does not imply approval or recommendation of the product by the University of California or the Department of Energy to the exclusion of others that may be suitable.

* Standard for Metric Practice, American Society for Testing and Materials, Philadelphia, PA, ASTM E 380-76ε (1976).

CONTENTS

ABBREVIATIONS AND SYMBOLS

AFNOL	polymerization product of primarily DINOL and 4,4-dinitropimeloyl chloride
AN	ammonium nitrate
AP	ammonium perchlorate
ATBC	acetyl tributyl citrate
AWRE	Atomic Weapons Research Establishment, U.K.
b.p.	boiling point
BDNPA-F	bis(2,2-dinitropropyl) acetal/bis(2,2-dinitropropyl) formal, 50/50
BDNPF	bis(2,2-dinitropropyl) formal
BEAF	1,2-ethanediol bisdifluoronitroacetate
BKW	Brinkley-Kistiakowski-Wilson (equation of state)
BTF	benzotrifuroxan
c_b	calculated bulk sound velocity
c_ℓ	longitudinal shear sound velocity
C_P	specific heat
c_s	transverse shear sound velocity
CAB	cellulose acetate butyrate
CEF	tris-β-chloroethyl phosphate
CJ	Chapman-Jouguet
CTE	coefficient of thermal expansion
D	detonation velocity
d_c	critical diameter
DATB	1,3-diamino-2,4,6-trinitrobenzene
dec.	decomposition
DEGN	diethylene glycol dinitrate
DFTNB	difluorotrinitrobenzene
DINOL	2,2,8,8-tetranitro-4,6-dioxa-1,9-nonanediol
DIPAM	3,3-diamino-2,2',4,4',6,6'-hexanitrobiphenyl
DMFA	N,N-dimethylformamide
DMSO	dimethylsulfoxide
DNPA	2,2-dinitropropyl acrylate
DNPN	4,4-dinitropentanonitrile
DNT	2,4-dinitrotoluene
DOP	dioctylphthalate
E	energy

EDNP	ethyl 4,4-dinitropentanoate
EGDN	ethylene glycol dinitrate
E_u	ultrasonic modulus
f	coefficient of friction
f.p.	freezing point
FEFO	bis(2-fluoro-2,2-dinitroethyl) formal
G*	complex shear modulus
H_{50}	drop weight sensitivity
HE	high explosive
HMX	1,3,5,7-tetranitro-1,3,5,7-tetrazacyclooctane
HNAB	2,2',4,4',6,6'-hexanitroazobenzene
HNS	2,2',4,4',6,6'-hexanitrostilbene
HVD	high velocity detonation
J(t)	creep compliance
JWL	Jones-Wilkins-Lee (equation of state)
K	degrees kelvin
$\mathcal{K}$	bulk modulus
LANL	Los Alamos National Laboratory†
LLNL	Lawrence Livermore National Laboratory
LSGT	large-scale gap test
LVD	low velocity detonation
m.p.	melting point
MEK	methyl ethyl ketone
MIBK	methyl isobutyl ketone
MNT	mononitrotoluene
MW	molecular weight
N	newton (pound-force)
n	refractive index
NC	nitrocellulose
NG	nitroglycerine
NM	nitromethane
NONA	nonanitroterphenyl
NQ	nitroguanidine

† As this report goes to press, the Los Alamos National Laboratory has not designated an acronymic abbreviation. We have therefore used LANL, which corresponds in style to the other facility acronyms used in this report.

NSWC	Naval Surface Weapons Center
P_{CJ}	Chapman-Jouguet pressure
PBX	plastic-bonded explosive
PETN	pentaerythritol tetranitrate
PR	Poisson's ratio
PX	Mason & Hanger-Silas Mason Co., Inc., Pantex Plant
R	molecular refraction
RDX	1,3,5-trinitro-1,3,5-triazacyclohexane
RMS	rheometric mechanical spectrometer
RTV	room-temperature vulcanizing
SI	Systeme Internationale (International System of Units)
SRI	Stanford Research Institute
SSGT	small-scale gap test
STP	standard temperature and pressure
T	temperature
T_g	glass transition temperature
TACOT	2,4,8,10-tetranitro-5H-benzotriazolo-[2,1-a]-benzotriazole
TATB	1,3,5-triamino-2,4,6-trinitrobenzene
Tetryl	2,4,6-trinitrophenylmethylnitramine
THF	tetrahydrofuran
TMD	theoretical maximum density
TNM	tetranitromethane
TNT	2,4,6-trinitrotoluene
V	volume
v	velocity
v.p.	vapor pressure
WLF	Williams-Landel-Ferry (shift equation)
ΔH_{det}	heat of detonation
ΔH_f	heat of formation
α	linear CTE
β	cubical CTE
Γ	adiabatic coefficient of expansion
γ	Grüneisen constant
ϵ	dielectric constant
λ	thermal conductivity
ν	sliding velocity
ρ	density

CONVERSION FACTORS

	Symbol	Unit system U.S./British	cgs	SI (m/k/s)[a]	Multiplication factor
Angle			deg	rad	1.745×10^{-2}
C-J pressure	P_{CJ}		bar	Pa	1.00×10^{5}
Creep compliance	J	1/psi (= in.^{2}/lbf)		m^2/N	1.450×10^{-4}
Density	ρ		g/cm^3	Mg/m^3	1
Detonation velocity	D		mm/μsec	km/s	1
Energy	E		cal/cm^2	J/m^2	4.184×10^{4}
Heat of detonation[b]	ΔH_{det}		cal/g	J/kg	4.184×10^{3}
Heat of formation[b]	ΔH_f		cal/g	J/kg	4.184×10^{3}
			kcal/mol	kJ/mol	4.184
Initial modulus	E_0	psi		Pa	6.895×10^{3}
Length			Å	m	10^{-10}
		mil		m	2.54×10^{-5}
Pressure	P	psi		Pa	6.895×10^{3}
			atm	Pa	1.01×10^{5}
			bar	Pa	1.00×10^{5}
Sliding velocity	ν	in./min		m/s	4.233×10^{-4}
		ft/sec		m/s	3.048×10^{-1}
Specific heat[b]	C_p	Btu/lb-°F	cal/g-°C	J/kg-K	4.184×10^{3}
Temperature	T	°F		K	$[(T_F-32)/1.8] + 273$
			°C	K	$T_C + 273$

CONVERSION FACTORS. (Continued)

	Symbol	Unit system: U.S./British	cgs	SI (m/k/s)[a]	Multiplication factor
Thermal conductivity[b]	λ	Btu/hr-ft-°F		W/m-K	1.73
			cal/cm-sec-°C	W/m-K	4.184×10^2
Thermal expansion	CTE	in./in.-°F		m/m-K	1.8
			cm/cm-°C	m/m-K	1
Vapor pressure	v.p.		mm Hg, Torr	Pa	1.333×10^2
Weight		lb		kg	4.536×10^{-1}

[a] In this column, the abbreviations used are those of the International System of Units (SI); in this system, degrees kelvin = K.
[b] Thermochemical Btu or calorie.

PROPERTIES OF CHEMICAL EXPLOSIVES AND EXPLOSIVE SIMULANTS

I. HIGH EXPLOSIVES

1. INTRODUCTION

High explosives are metastable compounds or mixtures that can react rapidly to give gaseous products at high temperature and pressure. The attendant expansion of these products is the mechanism by which explosives do useful work. High explosives are like primary explosives in that reaction can be initiated by shock and heat. High explosives, however, differ from primary explosives in three ways:

1. Small unconfined charges (1-2 g), even though ignited, do not transit easily from a burning or deflagration reaction to a detonation.
2. Electrostatic ignition is very difficult (except in explosive dust clouds).
3. Ignition of any sort requires considerably larger shocks.

2. MANUFACTURE

Pure explosives are usually synthesized by sulfuric/nitric-acid nitration of organic compounds. The product is separated from the mixed acids by filtration, purified, and dried.

TNT is one of the few pure explosives that can be fabricated directly by melting and casting into a desired shape. Most other materials must be diluted either with TNT (to make them castable) or with plastic (to make them pressable) before they can be fabricated into useful shapes.

The procedure used for fabricating castable, TNT-containing formulations is as follows: TNT is melted, and the desired solid ingredients are added with stirring. The molten mixture is then vacuum-cast into a mold. Cracking and variations in density and composition are minimized by careful control of the cooling rate.

Plastic-bonded explosives (PBX) are pressed from "molding" powders, which may be produced in several ways. A typical preparative method is the slurry technique: crystalline explosive and water are agitated in a container equipped with cover, condenser, and stirrer. A lacquer, which consists of the plastic (together with a plasticizer, if required) dissolved in a suitable solvent, is added to the slurry. The solvent is not a solvent for the HE but wets the crystalline surfaces better than water. The solvent is immiscible with water and has a high vapor pressure. It is removed by distillation, which causes the plastic phase to precipitate out onto the explosive as a coating. The plastic-explosive agglomerates into "beads" as stirring and solvent removal are continued. Finally, water is removed from the beads by filtering and drying. The product is the molding powder. Good molding powders have a high bulk density and are free-flowing and dustless.

PBX molding powder can be pressed into usable shapes by two methods: 1) compression molding with steel dies and 2) hydrostatic (or isostatic) pressing. In the latter method, the explosive is placed in rubber sacks and subjected to fluid pressure. With either method, consolidation of the molding powder to reasonable densities (97% of theoretical) is obtained at pressures between 12,000 and 20,000 psi (83 and 138 MPa) and molding temperatures between 25 and 120°C (298 and 393 K). An important and necessary feature of molding is the use of vacuum. The molding powder is normally evacuated to a pressure of less than 1 mm Hg (133 Pa) before pressing.

Both pressed and cast explosives are usually machined to final shape. Many intricate forms have been cut successfully. As a rule, the machining of explosives is similar to the machining of a conventional plastic, except that water is used as a cutting-tool coolant. New explosives are machined by remote control until their behavior under machining conditions has been carefully evaluated.

2.1. SPECIFICATIONS

Manufacture and testing of production explosives are controlled by specifications. Pertinent specifications are listed in Table 2-1.

Table 2-1. Specifications for manufacture and testing.

Material designation	Specification number	Title
		Explosives
AN	MIL-A-50460A	Military Specifications for Ammonium Nitrate, Technical.
AP	OS 11354	Navy Specification for Ammonium Perchlorate.
BDNPA-F	WS-1141	Weapons Specification for Mixture of Bis(2,2-dinitropropyl) acetal-Bis(2,2-dinitropropyl) formal.
Comp A-3, A-4	MIL-C-440B	Military Specification for Compositions A-3 and A-4.
Comp A-5	MIL-E-14970	Military Specification for Composition A-5.
Comp B	MIL-C-401C	Military Specification for Composition B.
Comp B-3	MIL-C-45113	Military Specification for Composition B-3.
Comp C-4	MIL-C-45010	Military Specification for Composition C-4.
Explosive D	JAN-A-166A	Military Specification for Explosive D.
FEFO	RM-253202	LLNL Material Specification for Liquid Explosive Bis(2-fluoro-2,2-dinitroethyl) formal (FEFO).

Table 2-1. Specifications for manufacture and testing. (Continued)

Material designation	Specification number	Title
		Explosives
HBX	MIL-E-22267A	Military Specification for HBX-Type Explosives.
HMX	MIL-H-45444	Military Specification for HMX.
HNAB	SS274590	Sandia Specification for Synthesis of HNAB (Hexanitroazobenzene).
LX-04	RM-252353	LLNL Material Specification for LX-04 Molding Powder.
LX-07	RM-253379	LLNL Material Specification for LX-07 Molding Powder.
LX-09	RM-253200	LLNL Material Specification for LX-09 Molding Powder.
LX-10	RM-253511	LLNL Material Specification for LX-10 Molding Powder.
LX-13	RM-253520	LLNL General Specification for LX-13.
LX-14-0	RM-253683	LLNL Material Specification for LX-14 Molding Powder.
LX-17-0	RM-255117	LLNL Material Specification for LX-17 High Explosive Molding Powder.
Minol-2	MIL-M-14745	Military Specification for Minol-2 Composition.
Octol	MIL-O-45445	Military Specification for Octol.
PBX-9007	PA-PD-711	Picatinny Arsenal: Purchase Description for Powder, Molding Compound Explosive (PBX). (PBX-9007).
PBX-9010	OAC-PD-112	Purchase Description for PBX-9010 Molding Powder.
PBX-9011	13Y-101030	LANL Material Specification for PBX-9011 Molding Powder.
PBX-9205	13Y-103317	LANL Material Specification for PBX-9205 Manufactured by the Slurry Method.

Table 2-1. Specifications for manufacture and testing. (Continued)

Material designation	Specification number	Title
		Explosives
PBX-9404	13Y-103159	LANL Material Specification for PBX-9404 Molding Powder.
	RM-252336	LLNL Material Specification for PBX-9404 Molding Powder.
PBX-9407	13Y-109098	LANL Material Specification for PBX-9407 Molding Powder.
PBX-9501	13Y-109643	LANL Material Specification for PBX-9501 Molding Powder.
PBX-9502	13Y-188727	LANL Material Specification for PBX-9502 Molding Powder.
PBX-9503	13Y-190273	LANL Material Specification for PBX-9503.
PETN	MIL-P-387	Military Specification for Pentaerythritol Tetranitrate (PETN).
RDX	MIL-R-398	Military Specification for RDX.
TATB	13Y-188025	LANL Material Specification for TATB (Triamino-trinitrobenzene) Molding Powder.
	RM-254959	LLNL Material Specification for Ultrafine TATB.
Tetryl	JAN-T-339	Joint Army-Navy Specification for Tetryl (Trinitrophenylmethylnitramine).
TNT	MIL-T-248	Military Specification for TNT.
XTX-8003	13Y-104481	LANL Material Specification for XTX-8003 Extrudable Explosive.
XTX-8004	13Y-189496	LANL Material Specification for XTX-8004 Extrudabl Explosive.
		Binders
Estane 5702 F-1	RM-253682	LLNL Material Specification for Elastomer, Polyurethane.

Table 2-1. Specifications for manufacture and testing. (Continued)

Material designation	Specification number	Title
		Binders
Estane 5740 X-2	13Y-101031	LANL Material Specification for Estane 5740 X-2.
Fluoro-elastomer	RM-252988	LLNL Material Specification for Uncured Fluoro-elastomer binder.
pDNPA	RM-253201	LLNL Material Specification for 2,2-Dinitropropyl Acrylate Polymer (pDNPA) Plastic Binder.
Kel-F 800	13Y-188481	LANL Material Specification for Kel-F 800.
Polystyrene	MIL-P-55026	Military Specification for Polystyrene, Unmodified (For Use as a Binder in Explosives).
Sylgard 182	13Y-104480	LANL Material Specification for Dow Corning Resin 93-022 (Aerospace Grade Sylgard 182).
		Explosive Parts
	RM-253391	LLNL Specification for Mechanical Properties Testing of Plastic-Bonded High Explosive Parts.
	RM-252356	LLNL General Specifications for Plastic-Bonded High Explosives.
	RM-255693	LLNL Minimum Requirements for LX-17 Parts.

3. NAMES AND FORMULATIONS

This section consists of Tables 3-1 through 3-6, which list the names and formulations of the various materials for which data are reported in this handbook. The high explosive (HE) compositions are arranged by major component in Table 3-6.

Table 3-1. Pure explosive compounds.

Material[a]	Chemical name[b]	Other designations	Color
AN	Ammonium nitrate		Clear
AP	Ammonium perchlorate		White
BTF	Benzotris[1,2,5]oxadiazole, 1,4,7-trioxide	Benzotrifuroxan; Hexanitrosobenzene; Benzotrifurazan-N-oxide	Buff
DATB	2,4,6-Trinitro-1,3-benzenediamine	1,3-Diamino-2,4,6-trinitrobenzene	Yellow
DEGN	2,2'-Oxybisethanol, dinitrate	Diethylene glycol dinitrate; Dinitrodiglycol	Clear
DIPAM	2,2',4,4',6,6'-Hexanitro-[1,1-biphenyl]-3,3'-diamine	3,3'-Diamino-2,2',4,4',6,6'-Hexanitrobiphenyl; Hexanitrodiphenyl amine hexite; Dipicramide	-
DNPA	2,2-Dinitropropyl acrylate		Off-white
EDNP	Ethyl 4,4-dinitropentanoate	Ethyl 4,4-dinitrovalerate	Yellow
Explosive D	Ammonium picrate	Dunnite	Yellow/red
FEFO	1,1'-[Methylenebis(oxy)]bis-[2-fluoro-2,2-dinitroethane]	Bis(2-fluoro-2,2-dinitroethyl) formal	Straw

Table 3-1. Pure explosive compounds. (Continued)

Material[a]	Chemical name[b]	Other designations	Color
HMX	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine	1,3,5,7-Tetranitro-1,3,5,7-tetraza-cyclooctane; Cyclotetramethylene tetranitramine; Octogen	White
HNAB	Bis(2,4,6-trinitrophenyl)-diazene	2,2'4,4',6,6'-Hexa-nitroazobenzene	Reddish-orange
HNS	1,1'-(1,2-Ethenediyl)bis-[2,4,6-trinitrobenzene]	2,2',4,4',6,6'-Hexa-nitrostilbene	Yellow
Lead azide			White
Lead styphnate	2,4,6-Trinitro-1,3-benzene-diol, lead salt	Lead trinitro-resorcinate	Orange-yellow/brown
NC (12% N)[c]	Partially nitrated cellulose	Nitrocellulose (lacquer grade); Cellulose trinitrate; Piroksilin; Pyroxylin	White
NC (13.35% N, min)[c]	Partially nitrated cellulose	Nitrocellulose; Guncotton	White
NC (14.14% N)[c]	Partially nitrated cellulose		White
NG	1,2,3-Propanetriol, trinitrate	Nitroglycerin; Glycerolnitrate	Clear
NM	Nitromethane		Clear
NQ	Nitroguanidine	Picrite	White
PETN	2,2-Bis[(nitrooxy)methyl]-1,3-propanediol, dinitrate	Pentaerythritol tetranitrate; Penthrite; TEN; Nitropenta	White
Picric acid	2,4,6-Trinitrophenol	Melinite; Perlit; Lyddit; 1-Hydroxy-2,4,6-trinitrobenzene	Yellow

Table 3-1. Pure explosive compounds. (Continued)

Material[a]	Chemical name[b]	Other designations	Color
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine	1,3,5-Trinitro-1,3,5-triazacyclohexane Cyclotrimethylene trinitramine; Hexogen; Cyclonite; Gh; T4; 1,3,5-Trinitrotrimethylene-triamine	White
TACOT	2,4,8,10-Tetranitro-5H-benzo-triazolo-[2,1-a]-benzo-triazol-6-ium, hydroxide, inner salt	Tetranitrodibenzo-1,3a,4,6a-tetrazapentalene	Red-orange
TATB	2,4,6-Trinitro-1,3,5-benzene-triamine	1,3,5-Triamino-2,4,6-trinitrobenzene	Bright yellow
Tetryl	N-Methyl-N,2,4,6-tetranitro-benzenamine	2,4,6-Trinitrophenyl-methylnitramine; N-methyl-N,2,4,6-tetranitroaniline; Tetranitromethyl-aniline; Pyronite; CE	Yellow/buff
TNM	Tetranitromethane		Clear
TNT	2-Methyl-1,3,5-trinitro-benzene	2,4,6-Trinitrotoluene Trotyl; T; Tolit	Buff/brown

[a] Properties of these materials are summarized in the data sheets (Section IV).
[b] The chemical names are listed in the Chemical Abstracts Index Guide (American Chemical Society, Columbus, OH, 1977+).
[c] Nitrocellulose is not, strictly speaking, a single chemical compound. Different grades are commercially available; the grade denotes the degree of nitration. For this handbook, we cite data, where possible, that is characteristic of lacquer-grade nitrocellulose (12.0% N) and guncotton (13.35% N, min). Lacquer-grade nitrocellulose is not an explosive but an energy-contributing plastic binder in PBX-9404. The maximum possible nitration is 14.14%.

Table 3-2. Cast explosives: names and formulations.

Explosive[a]	Formulation (wt%)[b] TNT	RDX	Other ingredients	
Amatol 80/20	20	--	AN	80
Baratol	24	--	$Ba(NO_3)_2$	76
Boracitol	40	--	Boric acid	60
Comp A-3	--	91	Wax	9
Comp A-5	--	98.5-99	Stearic acid	1.5-1
Comp B, Grade A[c]	36	63	Wax	1
Comp B-3	40	60		
Cyclotol[d] 75/25	25	75		
H-6	30	45	Al Wax ($CaCl_2$	20 5 0.5)
HBX-1	38	40	Al Wax ($CaCl_2$	17 5 0.5)
HBX-3	29	31	Al Wax ($CaCl_2$	35 5 0.5)
Minol-2	40	--	Al AN	20 40
Octol	25	--	HMX	75
Pentolite[d]	50	--	PETN	50
Tritonal	80	--	Al	20

[a] Properties of most of these materials are summarized in the data sheets (Section IV).
[b] The wt% values are nominal and subject to some variation.
[c] Comp B, Grade A is formulated as a 60/40 RDX/TNT mixture, but high-quality castings usually are higher in RDX content because a TNT-rich section is removed from the top of the casting.
[d] There are several cyclotols and pentolites. The most common cyclotol is RDX/TNT 75/25. The properties of cyclotol 60/40 are listed as Comp B-3. The most common pentolite is PETN/TNT 50/50.

Table 3-3. Plastic-bonded explosives: names and formulations.

Explosive[a]	Other designations	Formulation: Ingredient	Formulation: wt%	Color
LX-04-1	PBHV-85/15	HMX	85	Yellow
		Viton A	15	
LX-07-2	RX-04-BA	HMX	90	Orange
		Viton A	10	
LX-09-0	RX-09-CB	HMX	93	Purple
		pDNPA	4.6	
		FEFO	2.4	
LX-09-1		HMX	93.3	Purple
		pDNPA	4.4	
		FEFO	2.3	
LX-10-0	RX-04-DE	HMX	95	Blue-green spots on white
		Viton A	5	
LX-10-1	RX-04-EA	HMX	94.5	Blue-green spots on white
		Viton A	5.5	
LX-11-0	RX-04-PI	HMX	80	White
		Viton A	20	
LX-14-0	RX-04-EQ	HMX	95.5	Violet spots on white
		Estane 5702-F1	4.5	
LX-15	RX-28-AS	HNS-I	95	Beige
		Kel-F 800	5	
LX-16	RX-15-AD	PETN	96	White
		FPC 461	4	
LX-17-0	RX-03-BB	TATB	92.5	Yellow
		Kel-F 800	7.5	
PBX-9007	PBX-9007 Type B	RDX	90	White or mottled gray[b]
		Polystyrene	9.1	
		DOP	0.5	
		Rosin	0.4	
PBX-9010		RDX	90	White
		Kel-F 3700	10	

Table 3-3. Plastic-bonded explosives: names and formulations. (Continued)

Explosive[a]	Other designations	Formulation: Ingredient	Formulation: wt%	Color
PBX-9011	X-0008	HMX	90	Off-white
		Estane 5703-F1	10	
PBX-9205		RDX	92	White
		Polystyrene	6	
		DOP	2	
PBX-9404	PBX-9404-03	HMX	94	White or blue
		NC (12.0% N)	3	
		CEF	3	
PBX-9407		RDX	94	White or black[b]
		FPC 461	6	
PBX-9501	X-0242	HMX	95	White
		Estane	2.5	
		BDNPA-F	2.5	
PBX-9502	X-0290	TATB	95	Yellow
		Kel-F 800	5	
PBX-9503	X-0351	HMX	15	
		TATB	80	Purple
		Kel-F 800	5	
PBX-9604	RX-10-AB	RDX	96	
		Kel-F 800	4	

[a] Properties of most of these materials are summarized in the data sheets (Section IV).
[b] Color depends on graphite content.

Table 3-4. Miscellaneous explosives: names and formulations.

Explosive[a]	Other designations	Formulation: Ingredient	wt%	Color
Black Powder	Black gunpowder	KNO_3	75	Gray to black
		Charcoal	15	
		Sulfur	10	
Comp C-3		RDX	77	Yellow
		TNT	4	
		DNT	10	
		MNT	5	
		Tetryl	3	
		NC	1	
Comp C-4	Harrisite	RDX	91	Light brown
		Di(2-ethylhexyl) sebacate	5.3	
		Polyisobutylene	2.1	
		Motor oil	1.6	
EL-506A	Detasheet	PETN	85	Red
		Binder	15	
EL-506C	Detasheet	PETN	63	Olive
		NC (12.3% N)	8	
		ATBC	29	
LX-01	NTN, RX-01-AA	NM	51.7	Clear
		TNM	33.2	
		1-Nitropropane	15.1	
LX-02-1	EL-506 L-3 RX-02-AC	PETN	73.5	Buff
		Butyl rubber	17.6	
		ATBC	6.9	
		Cab-O-Sil	2.0	
LX-08	RX-02-AM	PETN	63.7	Blue
		Sylgard 182	34.3	
		Cab-O-Sil	2.0	
LX-13		PETN	80	White
		Sylgard 182	20	

Table 3-4. Miscellaneous explosives: names and formulations. (Continued)

Explosive[a]	Other designations	Formulation		Color
		Ingredient	wt%	
MEN-II	RX-01-AC	NM	72.2	Clear
		Methanol	23.4	
		Ethylenediamine	4.4	
XTX-8003	Extex	PETN	80	White
		Sylgard 182	20	
XTX-8004	X-0208	RDX	80	White
		Sylgard 182	20	

[a] Properties of most of these materials are summarized in the data sheets (Section IV).

Table 3-5. Additives and binders.

Material[a]	Chemical name	Other designations	Color
BDNPA-F	Bis(2,2-dinitropropyl) acetal/bis(2,2-dinitropropyl) formal, 50/50 wt%		Straw
Cab-O-Sil M-5		Amorphous silicon oxide	White
CEF	Tris-β-chloroethylphosphate		Clear
DOP	Di(2-ethylhexyl) phthalate	Dioctylphthalate	Clear
Estane 5702-F1		Polyurethane solution system	Light amber
FPC 461	Vinyl chloride/chlorotrifluoroethylene copolymer, 1.5:1		White
Kel-F 800	Chlorotrifluoroethylene/vinylidine fluoride copolymer, 3:1		Off-white
Polystyrene			Clear
Sylgard 182	Poly(dimethylsiloxane)	Silicone resin	Light straw
Viton A	Vinylidine fluoride/hexafluoropropylene copolymer, 60/40 wt%		White

[a] Properties of these materials are summarized in the data sheets (Section IV).

Table 3-6. Explosive compositions by major HE component.

Major component (wt%)		Other constituents (wt%)	Designation
AN	80	TNT 20	Amatol 80/20
	40	TNT 40 Al 20	Minol-2
HMX	95.5	Estane 5702-F1 4.5	LX-14
	95	Viton A 5	LX-10-0,
	95	Estane 2.5 BDNPA-F 2.5	PBX-9501
	94.5	Viton A 5.5	LX-10-1
	94	NC 3 CEF 3	PBX-9404-3
	93	FEFO 2.4 DNPA 4.6	LX-09-1
	90	Viton A 10	LX-07-2
	90	Estane 5703-F1 10	PBX-9011
	85	Viton A 15	LX-04-1
	80	Viton A 20	LX-11
	75	TNT 25	Octol 75/25
HNS-I	95	Kel-F 800 5	LX-15
NM	72.2	CH_3OH 23.4 Ethylene diamine 4.4	MEN-II
	51.7	TNM 33.2 Nitropropane 15.1	LX-01
PETN	96	FPC 461 4	LX-16-0
	85	Binder 15	EL-506A
	80	Sylgard 182 20	LX-13, XTX-8003
	73.5	Rubber 17.6 ATBC 6.9 Cab-O-Sil 2.0	LX-02-1
	63.7	Rubber 34.3 Cab-O-Sil 2.0	LX-08
	50	TNT 50	Pentolite 50/50
RDX	98.5-99	Wax 1.0-1.5	Comp A-5
	96	Kel-F 800 4	PBX-9604
	94	FPC 461 6	PBX-9407
	92	PS 6 DOP 2	PBX-9205
	91	DEHS 5.3 PIB 2.1 Motor oil 1.6	Comp C-4
	91	Wax 9	Comp A-3
	90	PS 9.1 DOP 0.5 Rosin 0.4	PBX-9007
	90	Kel-F 3700 10	PBX-9010
	80	Sylgard 182 20	XTX-8004
	77	TNT 4.0 DNT 10.0 MNT 5.0 NC 1.0 Tetryl 3.0	Comp C-3
	75	TNT 25	Cyclotol 75/25
	63	TNT 36 Wax 1	Comp B
	60	TNT 40	Cyclotol 60/40, Comp B-3
	45	TNT 30 Al 20 Wax 5 ($CaCl_2$ 0.5)	H-6
	40	TNT 38 Al 17 Wax 5 ($CaCl_2$ 0.5)	HBX-1
	31	TNT 29 Al 35 Wax 5 ($CaCl_2$ 0.5)	HBX-3

Table 3-6. Explosive compositions by major HE component. (Continued)

Major component (wt%)		Other constituents (wt%)	Designation
TATB	95	Kel-F 800 5	PBX-9502
	92.5	Kel-F 800 7.5	LX-17-0
	80	HMX 15 Kel-F 800 5	PBX-9503
TNT	50	PETN 50	Pentolite 50/50
	40	AN 40 Al 40	Minol-2
	40	Boric acid 60	Boracitol

4. PHYSICAL PROPERTIES

This section contains information relating to selected physical constants and properties of HEs of interest. These properties are:

Physical state and density (ρ),

Molecular weight (MW) and atomic composition,

Melting point (m.p.), boiling point (b.p.), and vapor pressure (v.p.),

Crystallographic and optical properties.

The physical states, densities, molecular weights and elemental compositions are listed in Table 4-1. For materials that are pure chemical compounds, molecular weights and molecular formulas are given; for mixtures, an arbitrary molecular weight of 100 is assigned, and an empirical formula corresponding to this weight is given. For such mixtures, the weight percentage of an element is given by the product of the atomic weight and its subscript in the empirical formula. Melting points, boiling points, and vapor pressures are shown in Table 4-2 and in Fig. 4-1; crystallographic and optical properties are listed in Table 4-3.

Many properties of explosives are density-dependent. For calculations for mixtures, some useful auxiliary relationships between composition and density are as follows:[1]

$$\rho(\text{TMD}) = \frac{\sum m_i}{\sum (m_i/\rho_i)} = \frac{\sum (v_i \rho_i)}{v_i} ,$$

$$V_i = W_i(\rho_0/\rho_i) = \frac{v_i}{\sum v_i} = \frac{100\ m_i/\rho_i}{\sum (m_i/\rho_i)} ,$$

$$W_i = \frac{100\ v_i \rho_i}{\sum (v_i \rho_i)} = \frac{100\ m_i}{\sum m_i} ,$$

$$\text{Void } V_i = 1 - (\rho_0/\text{TMD}) ,$$

where TMD is theoretical maximum density, m is mass, v is volume, W is weight percent, V is volume percent, ρ is theoretical density, subscript i designates the component, and ρ_0 is the actual density of the mixture.

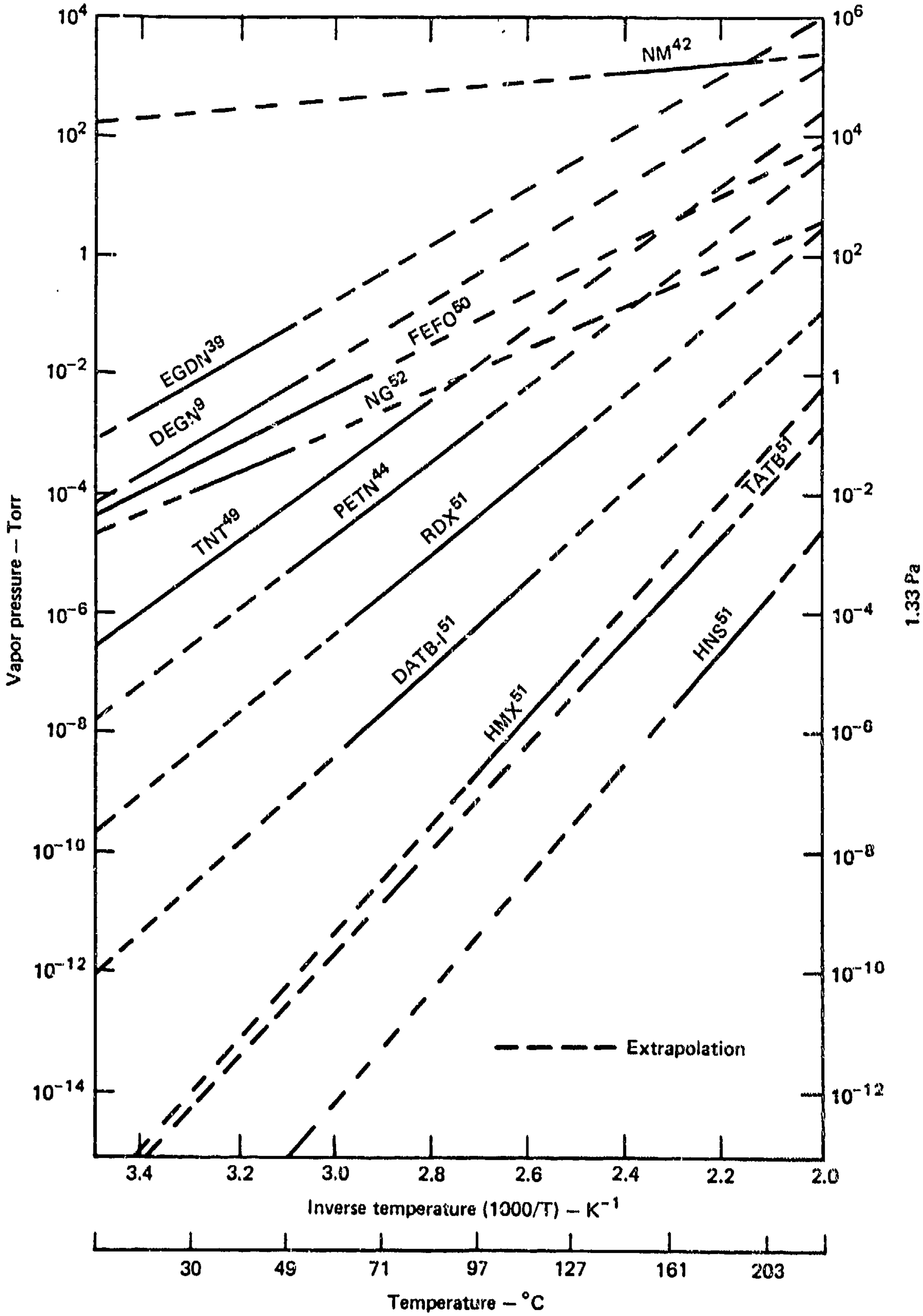


Fig. 4-1. Vapor pressure (v.p.) of explosives as a function of temperature.

Table 4-1. Density, physical state and atomic composition of explosives and additives.

Material	Physical state	Density, ρ [g/cm^3 (Mg/m^3)] TMD	Nominal	Ref.	MW	Elemental Composition C	H	N	O	Other	Ref.
Amatol 80/20	Solid	1.710	1.46 cast	2	100	0.62	4.44	2.26	3.53	--	3
AN	Solid	1.725	1.72	2	80.05	--	4	2	3	--	2
AP	Solid	1.95	--	4	117.5	--	4	1	4	Cl: 1	2
Baratol	Solid	2.63	2.60–2.61	--	100	0.74	0.53	0.90	2.38	Ba: 0.29	3
BDNPA-F	Liquid	1.383–1.397 at 25°C	--	5							
Black powder	Solid	≤2.0	∿1.91–∿1.95	6		∿10–∿12	∿0.5	∿11	∿36	K: ∿29 S: ∿10 Ash: ∿0.5	6
Boracitol	Solid	--[a]	1.53–1.54	--	100	1.23	3.79	0.53	3.97	B: 0.97	3
BTF	Solid	1.901	1.87	--	252.1	6	--	6	6	--	
Cab-O-Sil	Solid	2.3	2.2	7	60.09	--	--	--	2	Si: 1	
CEF	Liquid	1.425	--	--	285.5	6	12	--	4	Cl: 3 P: 1	
Comp A-3	Solid	1.672	1.65 pressed	8	100	1.87	3.74	2.46	2.46	--	3
Comp A-5	Solid	1.757	1.70 pressed	8	100	1.41–1.44	2.82–2.88	2.66–2.67	2.66–2.67	--	3
Comp B, Grade A[b]	Solid	1.742	1.71	--	100	2.03	2.64	2.18	2.67	--	3

Table 4-1. Density, physical state and atomic composition of explosives and additives. (Continued)

Material	Physical state	Density, ρ [g/cm^3 (Mg/m^3)]		Ref.	MW	Elemental Composition					Ref.
		TMD	Nominal			C	H	N	O	Other	
Comp B-3c	Solid	1.75	1.72	--	100	2.05	2.51	2.15	2.67	--	3
Comp C-3	Putty-like solid	---	1.58-1.62	--	100	1.90	2.83	2.34	2.60	--	3
Comp C-4	Putty-like solid	1.67	1.64-1.66	14	100	1.82	3.54	2.46	2.51		3
Cyclotol 75/25	Solid	1.77	1.75-1.76	--	100	1.78	2.58	2.36	2.69		3
Cyclotol 60/40	Solid	---	1.68 cast	--	100	2.04	2.50	2.15	2.68	--	3
DATB	Solid	1.837	1.79	--	243.1	6	5	5	6	--	
DEGN	Liquid	1.39	---	9	196	4	8	2	7	--	9
DIPAM	Solid	1.79	---	10	454.1	12	6	8	12	--	
DNPA	Solid	1.47	---	--	204.1	6	8	2	6		
DOP	Liquid	0.986	---	--	390.6	24	38	--	4		
EDNP	Liquid	1.28	---	--	220.2	7	12	2	6		--
EL-506A	Flexible solid	---	1.48	--	100	2.41	4.29	1.08	3.27	--	3
EL-506C	Flexible solid	1.483	1.48	11	100	3.25	5.49	0.87	2.68	--	3
Estane 5702-F1	Rubbery solid	---	1.18	12	100	5.14	7.50	0.19	1.76	--	3

Table 4-1. Density, physical state and atomic composition of explosives and additives. (Continued)

Material	Physical state	Density, ρ [g/cm³ (Mg/m³)] TMD	Nominal	Ref.	MW	Elemental Composition C	H	N	O	Other	Ref.
Explosive D	Solid	1.717	1.63	2	246	6	6	4	7	--	2
FEFO	Liquid	1.607	--	--	320.1	5	6	4	10	F: 2	
FPC 461	Solid	--	1.70	13	$(210)_n$	5	4.5	--		Cl: 2.5 F: 3	
H-6	Solid	1.791	1.75	14	100	1.89	2.59	1.61	2.01	Al: 0.74 Ca: 0.005 Cl: 0.009	3
HBX-1	Solid	1.76	1.71 cast 1.74 pressed	15 15	100	2.06	2.62	1.57	2.07	Al: 0.63 Ca: 0.005 Cl: 0.009	3
HBX-3	Solid	1.882	1.84-1.85	14	100	1.66	2.18	1.21	1.60	Al: 1.29 Ca: 0.005 Cl: 0.009	3
HMX	Solid	1.90	1.89	16	296.2	4	8	8	8	--	
HNAB-I	Solid	1.799	--	17	452.2	12	4	8	12	--	
HNAB-II	Solid	1.750	--	17	452.2	12	4	8	12	--	
HNS	Solid	1.740	1.72	18,19	450.3	14	6	6	12	--	
Kel-F 800	Solid	--	2.02	20	$(413.5)_n$	8	2	--	--	Cl: 3 F: 11	3
Lead azide	Solid	4.80	4.3 dextrin.		291	--	--	6	--	Pb: 1	2

Table 4-1. Density, physical state and atomic composition of explosives and additives. (Continued)

Material	Physical state	Density, ρ [g/cm^3 (Mg/m^3)]		Ref.	MW	Elemental Composition					Ref.
		TMD	Nominal			C	H	N	O	Other	
Lead styphnate	Solid	3.06	3.02	21	468	6	3	3	9	Pb: 1	2
LX-01-0	Liquid	1.23	--	--	100	1.52	3.73	1.69	3.39	--	3
LX-02-1	Putty-like solid	1.44	1.43-1.44	--	100	2.77	4.86	0.93	2.99	Si: 0.03	3
LX-04-1	Solid	1.889	1.86-1.87	--	100	1.55	2.58	2.30	2.30	F: 0.52	3
LX-07-2	Solid	1.892	1.86-1.87	--	100	1.48	2.62	2.43	2.43	F: 0.35	3
LX-08-0	Putty-like solid	1.439	≥1.42	--	100	1.93	4.39	0.81	2.95	Si: 0.50	3
LX-09	Solid	1.867	1.84-1.85	--	100	1.43	2.74	2.59	2.72	F: 0.02	3
LX-10	Solid	1.896	1.86-1.87	22	100	1.41-1.42	2.66	2.57-2.58	2.57-2.58	F: 0.16-0.17	3
LX-11-0	Solid	--	1.87-1.88	--	100	1.61	2.53	2.16	2.16	F: 0.70	3
LX-13 (See XTX-8003)											
LX-14-0	Solid	1.849	1.83	--	100	1.52	2.92	2.59	2.66	--	3
LX-15	Solid	1.752	--	23	100	3.05	1.29	1.27	2.53	Cl: 0.04 F: 0.13	3
LX-16	Solid	1.767	1.59-1.60	24	100	1.61	2.52	1.22	3.64	F: 0.05	3

Table 4-1. Density, physical state and atomic composition of explosives and additives. (Continued)

Material	Physical state	Density, ρ [g/cm³ (Mg/m³)] TMD	Nominal	Ref.	MW	Elemental Composition C	H	N	O	Other	Ref.
LX-17-0	Solid	1.944	1.89-1.94	--	100	2.29	2.18	2.15	2.15	Cl: 0.054 F: 0.2	3
MEN-II	Liquid	1.017	--	--	100	2.06	7.06	1.33	3.10	--	3
Minol-2	Solid	--	1.70	2	100	1.23	2.88	1.53	2.56	Al: 0.74	3
NC (12.0% N)	Solid	1.653	1.50	25	$(262.6)_n$	6	7	2.25	9.5	--	
NC (13.35% N)	Solid	1.656	--	25	$(274.1)_n$	6	7	2.5	10	--	
NC (14.14% N)	Solid	1.659	--	--	$(297.1)_n$	6	7	3	11	--	25
NG	Liquid	1.596	--	--	227.1	3	5	3	9	--	
NM	Liquid	1.13 at 20°C (293 K)		--	61.0	1	3	1	2	--	
NQ	Solid	1.775	1.55-1.75	91	104.1	1	4	4	2	--	
Octol 75/25	Solid	1.843	1.80-1.82	--	100	1.78	2.58	2.36	2.69	--	3
PBX-9007	Solid	1.697	1.66	--	100	1.97	3.22	2.43	2.44	--	3
PBX-9010	Solid	1.822	1.79	--	100	1.39	2.43	2.43	2.43	Cl: 0.09 F: 0.26	3
PBX-9011	Solid	1.795	1.77	--	100	1.73	3.18	2.45	2.61	--	3
PBX-9205	Solid	1.72	1.68	--	100	1.83	3.14	2.49	2.51	--	3

Table 4-1. Density, physical state and atomic composition of explosives and additives. (Continued)

Material	Physical state	Density, ρ [g/cm^3 (Mg/m^3)] TMD	Density, ρ [g/cm^3 (Mg/m^3)] Nominal	Ref.	MW	Elemental Composition C	H	N	O	Other	Ref.
PBX-9404-3	Solid	1.865	1.83-1.84	--	100	1.40	2.75	2.57	2.69	Cl: 0.03 P: 0.01	3
PBX-9407	Solid	1.81	1.60-1.62[d]	--	100	1.41	2.66	2.54	2.54	Cl: 0.07 F: 0.09	3
PBX-9501	Solid	1.855	1.84	--	100	1.47	2.86	2.60	2.69		
PBX-9502	Solid	1.942	1.90	--	100	2.30	2.23	2.21	2.21	Cl: 0.038 F: 0.13	3
PBX-9503	Solid	1.936	1.88	27	100	2.16	2.28	2.26	2.26	Cl: 0.038	3
Pentolite 50/50	Solid	1.71	1.67	--	100	2.33	2.37	1.29	3.22	--	3
PETN	Solid	1.78	1.76	--	316.2	5	8	4	12	--	
Picric acid	Solid	1.76	1.60	--	229.1	6	3	3	7	--	
Polystyrene	Solid	1.12	1.05	28	$(104.2)_n$	8	8	-	-	--	
RDX	Solid	1.806	--	--	222.1	3	6	6	6	--	
Sylgard 182	Liquid	1.05	--	29	$(74.16)_n$	2	6	--	1	Si: 1	
TACOT	Solid	1.85	1.61	--	388.2	12	4	8	8	--	
TATB	Solid	1.938	1.88	--	258.2	6	6	6	6	--	
Tetryl	Solid	1.73	1.71	--	287.0	7	5	5	8	--	
TNM	Liquid	1.650 at 13°C (286 K)		--	196.0	1	-	4	8	--	

Table 4-1. Density, physical state and atomic composition of explosives and additives. (Continued)

Material	Physical state	Density, ρ [g/cm³ (Mg/m³)] TMD	Density, ρ [g/cm³ (Mg/m³)] Nominal	Ref.	MW	Elemental Composition C	H	N	O	Other	Ref.
TNT	Solid	1.654	1.5-1.6 cast; 1.63-1.64 pressed	--	227.1	7	5	3	6	--	
Viton A	Rubbery solid	--	1.8-1.9	30	$(187.1)_n$	5	3.5	--	--	F: 6.5	
XTX-8003	Putty curable to rubbery solid	1.556	$\gtrsim$1.53	--	100	1.80	3.64	1.01	3.31	Si: 0.27	3
XTX-8004	Putty curable to rubbery solid	1.579	$\gtrsim$1.55	--	100	1.62	3.78	2.16	2.43	Si: 0.27	3

[a] A TMD value based on boric acid and TNT is 1.52; however, some boric acid breaks down to B_2O_3 during vacuum casting at over 80°C (353 K). This has the effect of increasing the TMD by an unpredictable amount.

[b] Based on nominal composition of RDX/TNT/Wax 63/36/1. The wax was assumed to have the composition CH_2.

[c] Based on nominal composition RDX/TNT 60/40.

[d] Nominal density in detonator and booster applications.

Table 4-2. Melting points m.p., boiling points b.p., and vapor pressures v.p.

Material	m.p. °C	m.p. (K)	Ref.	b.p. °C	b.p. (K)	Ref.	v.p.[a] mm Hg	v.p.[a] (Pa)	Ref.
AFNOL	105-110	(378-383)			--			--	
AN	169	(442)	54	210 dec.	(483)			--	
AP	>220 dec.	(>493)	54	--	--		logP = 10.56 - 6283.7/T(K)		31
Baratol	79-80	(352-353)		--	--		0.1 at 100°C	(13.33 at 373 K)	
BDNPA-F	--	--		~150 at 0.01 mm	(~423 at 1.33 Pa)	5		-- --	
Boracitol	79-80	(352-353)			--			--	
BTF	198-200	(471-473)			--			--	
CEF	203	(476)	32		--			--	
Comp A-3	200	(473)	33		--			--	
Comp B, Grade A	~80	(~353)			--			--	
Comp B-3	79-80	(352-353)			--		0.1 at 100°C	(13.33 at 373 K)	
Comp C-4	--	--[b]			--			--	
Cyclotol 75/25	79-80	(352-353)			--		0.1 at 100°C	(13.33 at 373 K)	
DATB	286	(559)	34		--			(logP = 12.75 - 7492/T(K) at 92.8-176.8°C)	35
DEGN	--	--		160-161	(433-434)	9	0.00593 at 25°C	(0.789 at 298 K)	9
DIPAM	304	(577)	10		--			--	
DOP	--	--		222-230	(495-503)	36	<0.06 at 150°C 1.2 at 200°C	(<8.0 at 423 K) (159.9 at 473 K)	36
EDNP	-6	(268)	37	83 at 0.05 mm	(356 at 6.7 Pa)	37		--	
EGDN				--	--		logP = 10.55 - 3476/T(K)		39
Explosive D	~280 dec.	(~553)	38	--	--			--	

Table 4-2. Melting points m.p., boiling points b.p., and vapor pressures v.p. (Continued)

Material	m.p. °C	m.p. (K)	Ref.	b.p. °C	b.p. (K)	Ref.	v.p.[a] mm Hg	v.p.[a] (Pa)	Ref.
FEFO	14.5	(287.5)	40	110 at 0.3 mm	(383 at 40 Pa)	40	2.14×10^{-4} at 25°C	(2.85×10^{-2} at 298 K)	
HMX	285	(558)	18		--		logP = 16.18 - 9154/T(K) at 97.6-129.3°C		41
							logP = 15.170 - 8596/T(K) at 188-213°C		41
								(logP = 12.98 - 8407/T(K) at 141.8-206.2°C)	35
							3×10^{-9} at 100°C	(4×10^{-7} at 373 K)	18
HNAB	220	(493)	18		--		1×10^{-7} at 100°C	(1.33×10^{-5} at 373 K)	18
HNS[c]	I: 315-316 dec.	(588-589 dec.)	19		--		I: logP = 14.084 - 9347/T(K)		10
	II: 318	(591)	18		--		II: 1×10^{-9} at 100°C	(1.33×10^{-7} at 373 K)	18
Lead azide	Dec.								
Lead styphnate	260-310 explodes	(533-583)							
LX-01-0	-54	(219)			--		29.0 at 25°C	(3866 at 298 K)	
LX-02-1		--[b]			--			--	
LX-04-1	Dec.>250	(>523)			--			--	
LX-07-2	Dec.>250	(>523)			--			--	
LX-08-0	129-135 with dec.	(402-408)			--			--	
LX-09	Dec.>280	(>553)			--			--	
LX-10	Dec.>250	(>523)			--			--	
LX-11	Dec.>250	(>523)			--			--	
LX-13 (See XTX-8003)									
LX-14-0	Dec.>270	(>543)			--			--	
LX-15	313	(586)	23		--			--	

Table 4-2. Melting points m.p., boiling points b.p., and vapor pressures v.p. (Continued)

Material	m.p. °C	m.p. (K)	m.p. Ref.	b.p. °C	b.p. (K)	b.p. Ref.	v.p.[a] mm Hg	v.p.[a] (Pa)	v.p. Ref.
LX-17							1.1×10^{-6} at 150°C	(1.46×10^{-4} at 423 K)	47
MEN-II	313	(586)	28		--			--	
NC(12.0% N)	Dec.>135	(>408)			--			--	
(13.35% N)	Dec.>135	(>408)			--			--	
NG	13.2	(286)					0.0015 at 20°C	(0.2 at 293 K)	
NM	-29	(244)		101	(374)	42	logP = 10.821 − 3905/(t + 260) 37 at 25°C	(4933 at 298 K)	42
NQ	257	(530)	26		--			(logP = 11.10 − 7452/T(K) at 129.2-199.8°C)	35
Octol	79-80	(352-353)					0.1 at 100°	(13.33 at 373 K)	
PBX-9007	Dec.>200	(>473)			--			--	
PBX-9010	Dec.>200	(>473)			--			--	
PBX-9011	Dec.>250	(>523)			--			--	
PBX-9205	Dec.>200	(>473)			--			--	
PBX-9404	Dec.>250	(>523)			--			--	
PBX-9407	Dec.>200	(>473)			--			--	
PBX-9501	Dec.>240	(>515)	43		--			--	
PBX-9502	Dec.>400	(>673)	33						
Pentolite 50/50	76	(349)			--		0.1 at 100°C	(13.33 at 373 K)	
PETN	140	(413)	18		--		8×10^{-5} at 100°C	(1.1×10^{-2} at 373 K) (logP = 16.26 − 7856/T(K) at 40.5-132.9°C)	18 35
							logP = 14.44-6352/T(K)		44
Picric acid	122	(395)	38		--		logP = 12.024 − 5729/T(K) at 58-103°C	(logP = 10.17 − 5488/T(K) at 40.5-132.9°C)	35
Polystyrene	240	(513)	28						

Table 4-2. Melting points m.p., boiling points b.p., and vapor pressures v.p. (Continued)

Material	m.p. °C	m.p. (K)	Ref.	b.p. °C	b.p. (K)	Ref.	v.p.[a] mm Hg	v.p.[a] (Pa)	Ref.
RDX	205 with dec.	(478)	45		—		logP = 11.87 − 5850/T(K) at 55.7–97.7°C		41
								(logP = 13.01 − 7014/T(K) at 70.7–174.2°C)	35
TACOT	Dec.>380	(>653)	46		—				
TATB	452	(725)	27		—		1.0 x 10^{-4} at 150°C	(1.33 x 10^{-2} at 423 K)	47
	Dec.>325	(>598)	35				3.2 x 10^{-3} at 175°C	(4.26 x 10^{-1} at 448 K)	47
							2.8 x 10^{-2} at 200°C	(3.72 at 473 K)	47
Tetryl	130	(403)			—		logP = 13.71 − 6776/T(K) at 85–106°C		33
TNM	14.2	(287)		125.7	(399)		13 at 25°C	(1733 at 298 K)	
							logP = 8.63 − 2260/T(K)		48
								(logP = 11.13 − 5410/T(K) at 46–124.5°C)	35
TNT	80.9	(354)			—		0.106 at 100°C	(14.13 at 373 K)	
							logP = 8.11 − 3850/T(K) at 200–350°C		39
							logP = 12.31 − 5175/T(K) at 15–75°C		39
							logP = 19.25 − 7372/T(K) at 12–40°C		39
								(logP = 12.60 − 5900/T(K) at 28.3–76.0°C)	35
XTX-8003	129–135	(402–408)			—		logP = 10.82 − 4908/T(K) at 80.8–95.2°C		33
XTX-8004	200 with dec.	(473)	33						

[a] 1 mm Hg = 1.33 x 10^2 Pa.
[b] No fixed melting point.
[c] Two types of HNS are in production: HNS-I, <10 μm particle size; and HNS-II, 100–300 μm particle size.

Table 4-3. Crystallographic and optical properties.[a]

Material	Polymorph	Unit cell dimensions[b] [Å (10^{-1} nm)] and angles	Crystal class	Space group	Refractive index (n)	Molecular refraction (R)	Ref.
AN							
(125-169.6°C)	I(ε) ρ=1.58-1.61	a=4.37	Cubic	Pm3m	1.530		53,55-58 85
(84-125°C)	II(δ) ρ=1.64-1.67	a=5.72 c=4.93	Tetragonal	$P\bar{4}2_1m$ or P4/mbm	ω=1.509 ε=1.585		
(32.3 to 84.1°C)	III(γ) ρ=1.64-1.66	a=7.72 b=5.85 c=7.16	Orthorhombic	Pnma	α=1.463 β=1.543 γ=1.600		
(-18 to 32.3°C)	IV(β) ρ=1.71-1.75	a=5.75 b=5.44 c=4.93	Orthorhombic	Pmmn			
(-18 to -150°C)	V(α) ρ=1.70-1.72	a=8.0 c=9.83	Tetragonal	$P4_2$	α=1.493 γ=1.623		
AP (<240°C)		a=9.23 b=7.45 c=5.82	Orthorhombic	Pnma	1.48		54,59-61
(>240°C)	ρ=1.71 obs.	a=7.67	Cubic	F43m			
BDNPA-F					1.462-1.464 at 25°C (298 K)		5
BTF	ρ=1.87	a=6.92 b=19.52 c=6.52	Orthorhombic	$Pna2_1$			62-63
Cab-O-Sil			Amorphous		1.46		7

Table 4-3. Crystallographic and optical properties.[a] (Continued)

Material	Polymorph	Unit cell dimensions[b] [Å (10^{-1} nm)] and angles	Crystal class	Space group	Refractive index (n)	Molecular refraction (R)	Ref.
DATB	I ρ=1.837	a=7.30 β=95.9 b=5.20 c=11.63		Pc			34
DEGN					1.450		38
DOP					1.485 at 25°C		36
Explosive D	(α) ρ=1.717	a=13.45 b=19.74 c=7.12	Orthorhombic	Icab	α=1.509 β=1.85 γ=1.915 } in Na light		38,64
(≥150°C)	(β)		Monoclinic				
HMX (103-162°C)	II(α)	a=15.14 b=23.89 c=5.91	Orthorhombic	Fdd2	α=1.561-1.565 β=1.562-1.566 γ=1.72-1.74	58 calc. 55.7 obs.	16,65-67 86
(<103°C)	I(β) ρ=1.903	a=6.54 β=124.3 b=11.05 c=8.70	Monoclinic	$P2_1/c$	α=1.589 β=1.594 γ=1.73	58 calc. 56.1 obs.	
(metastable)	III(γ)	a=10.95 β=119.4 b=7.93 c=14.61	Monoclinic	Pc_1P2/c	α=1.537 β=1.585 γ=1.666	58 calc. 55.4 obs.	
(162 m.p.)	IV(δ)	a=7.71 c=32.55	Hexagonal	$P6_122$	ε=1.566 ω=1.607	58 calc. 55.9 obs.	

Table 4-3. Crystallographic and optical properties.[a] (Continued)

Material	Polymorph	Unit cell dimensions[b] [Å (10^{-1} nm)] and angles	Crystal class	Space group	Refractive index (n)	Molecular refraction (R)	Ref.
HNAB (<185°C)	I ρ=1.795 calc. 1.799 obs.	a=10.15 β=97.3 b=8.26 c=10.06	Monoclinic	$P2_1/c$			17
(>185°C)	II ρ=1.744 calc. 1.750 obs.	a=10.63 β=102.6 b=21.87 c=7.59	Monoclinic	$P2_1/a$			17
HNS	I ρ=1.740	a=22.13 β=108.4 b=5.57 c=14.67	Monoclinic	$P2_1/c$			19,68
Kel-F 800					1.46		20
Lead azide	(α) ρ=4.68	a=6.63 b=16.25 c=11.31	Orthorhombic	Pnma	α=1.86 β=2.24 γ=2.64	35.1 obs.	69-71, 87
	(β) ρ=4.87	a=18.49 β=107.4 b=8.84 c=5.12	Monoclinic	C2/m			
Lead styphnate		a=10.06 β=91.9 b=12.58 c=8.05	Monoclinic		α=1.554 β=2.20 γ=2.22	73.9 obs.	21
NG					1.4732 at 20°C		2
NM (-268.8°C)		a=5.18 b=6.24 c=8.52		$P2_12_12_1$	1.641 at 20.4°C and 8.65 GPa		72, 88
NQ		a=17.58 b=24.85 c=3.59	Orthorhombic	Fdd2	α=1.526 β=1.694 γ=1.81	25.2 calc. 22.2 obs.	26,73, 89

Table 4-3. Crystallographic and optical properties.[a] (Continued)

Material	Polymorph	Unit cell dimensions[b] [Å (10^{-1} nm)] and angles	Crystal class	Space group	Refractive index (n)	Molecular refraction (R)	Ref.
PETN	I(α) ρ=1.778	a=9.38 c=6.70	Tetragonal	$P\bar{4}2_1/c$	ω=1.556 } in Na ε=1.551 } light		38,74-75
	II(β) ρ=1.716	a=13.29 b=13.49 c=6.83	Orthorhombic	Pcnb			
Picric acid		a=9.25 b=19.08 c=9.68	Orthorhombic	$C_{2}^{5}v$	1.620 at 122°C α=1.667 } β=1.699 } in Na γ=1.742 } light		30,76
Polystyrene		a=21.90 c=6.63	Rhombohedral		1.59-1.60		28
RDX	I(α) ρ=1.799	a=13.18 b=11.57 c=10.71	Orthorhombic	Pbca	α=1.578 } β=1.597 } at 20°C γ=1.602 }	43.7 calc. 41.4 obs.	38,45, 77-78
	II(β)	Unstable					
	III	Stable between 4->9.2 GPa					
Sylgard 182					1.430		29
TATB		a=9.01 α=108.6 b=9.03 β=91.8 c=6.81 γ=120	Triclinic	$P\bar{1}$	α=1.45 β=2.3 γ=3.1		79, 80
Tetryl		a=14.13 β=95.1 b=7.37 c=10.61	Monoclinic	$P2_1/c$	1.606 α=1.546 β=1.632 γ=1.74 calc.		38,81

Table 4-3. Crystallographic and optical properties.[a] (Continued)

Material	Polymorph	Unit cell dimensions[b] [Å (10^{-1} nm)] and angles	Crystal class	Space group	Refractive index (n)	Molecular refraction (R)	Ref.
TNM					1.4359		82
TNT	Phase A	a=21.28 β=111 b= 6.09 c=15.03	Monoclinic	$P2_1/c$	1.6 α=1.543, β=1.674, γ=1.717 } in Na light	44.3 calc. 49.6 obs.	68, 83
	Phase B	a=15.01 b= 6.11 c=20.02	Orthorhombic	$Pca2_1$			68

[a]Refractive indexes and molecular refractions are at 5893 Å and 25°C (589.3 nm and 298 K) unless otherwise stated; 10 Å = 1 nm.

[b]Unit cell dimensions are rounded to 0.01 Å.

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5. CHEMICAL PROPERTIES

This section gives information on heats of formation (ΔH_f), heats of detonation (ΔH_{det}), compatibility, and solubility.

5.1. HEATS OF FORMATION

Heats of formation are usually determined from combustion measurements in a bomb calorimeter; when experimental values are not available, they can be estimated by several methods.[1,28] The heat of formation (ΔH_f) refers to the enthalpy of the reaction

$$a\ C_{(s)} + \frac{b}{2} H_{2(g)} + \frac{c}{2} N_{2(g)} + \frac{d}{2} O_{2(g)} + \cdots \longrightarrow C_aH_bN_cO_d \cdots$$

at 1 atm (101 kPa) and 25°C (298 K). The sign convention is such that ΔH_f is negative when the above reaction is exothermic. Table 5-1 gives heats of formation for explosives and binders.

Table 5-1. Heats of formation (ΔH_f) for explosives and binders.

	ΔH_f				
Explosive	kcal/mol[a]	(kJ/mol)[b]	cal/g	(kJ/kg)[c]	Ref.
Amatol 80/20	-88.56	(-370.8)	-885.6	(-3708)	1
AN	-87.27	(-365.1)	-1084	(-4535)	31
AP	-70.58	(-295)	-601	(-2515)	2
Baratol	-70.6	(-296)	-706	-(2956)	1
BDNPA-F[d]	-46.38	(-194.1)	-464	(-1941)	
Boracitol	-256.6	(-1074)	-2566	(-10737)	1
BTF	+144.5	(+605)	+573	(-2397)	1
Cab-O-Sil	-215.94	(-903.5)	-3594	(-15037)	
CEF	-300	(-1255)	-1051	(-4397)	

Table 5-1. Heats of formation (ΔH_f) for explosives and binders. (Continued)

	ΔH_f				
Explosive	kcal/mol[a]	(kJ/mol)[b]	cal/g	(kJ/kg)[c]	Ref.
Comp A-3	+2.84	(+11.9)	+28.4	(+119)	1
Comp A-5	+6.1	(+25.5)	+61	(+255)	1
Comp B, Grade A[e]	+1.28	(+5.38)	+12.85	(+53.8)	1
Comp B-3	+1.15	(+4.81)	+11.5	(+48.1)	1
Comp C-3[e]	+3.74	(+15.6)	+37.4	(+156.4)	1
Comp C-4[e]	+3.33	(+13.9)	+33.3	(+139)	1
Cyclotol 60/40	(See Comp B-3)				
Cyclotol 75/25	+3.21	(+13.4)	+32.1	+134	1
DATB	-23.6	(-98.7)	-97.1	(-406)	28
DEGN	-99.4	(-416)	-507	(-2121)	3
DIPAM	-6.8	(-28.45)	-15.0	(-62.7)	28
DNPA	-110	(-460)	-539	(-2255)	1
DOP	-268.2	(-1122)	-687	(-2874)	1
EDNP	-140	(-585.8)	-636	(-2661)	1
EL-506A	-39.9	(-167)	-399	(-1669)	1
EL-506C	-42.5	(-178)	-424	(-1778)	1
Estane 5702-F1	-95	(-397)	-950	(-3975)	29
Estane 5704-X2	-95	(-397)	-950	(-3975)	29
Explosive D	-94	(-393)	-382	(-1598)	3
FEFO	-177.5	(-742.7)	-554.5	(-2320)	1
FPC 461	-190	(-795.0)	-909.5	(-3805)	1
H-6	-1.75	(-7.31)	-17.48	(-73.1)	1
HBX-1	-2.64	(-11.04)	-26.4	(-110.4)	1
HBX-3	-2.60	(-10.89)	-26.02	(-108.9)	1

Table 5-1. Heats of formation (ΔH_f) for explosives and binders. (Continued)

	ΔH_f				
Explosive	kcal/mol[a]	(kJ/mol)[b]	cal/g	(kJ/kg)[c]	Ref.
HMX	+17.93	(+75.02)	60.5	(+253.1)	1
HNAB	+67.9	(+284.1)	+150.2	(+628)	28
HNS	+18.7	(+78.2)	+41.5	(+174)	28
Kel-F 800[f]	-578	(-2418)	-1398	(-5848)	1
Kel-F 3700[f]	-161	(-674)	-1382	(-5783)	1
Lead azide	+112	(+469)	+385	(+1611)	3
Lead styphnate	-200.0	(-837)	-427.1	(-1787)	3
LX-01-0	-27.5	(-115.1)	-275	(-1151)	1
LX-02-1[e]	-49.1	(-205.4)	-491	(-2054)	1
LX-04-1	-21.5	(-90.0)	-215	(-900)	1
LX-07-2	-12.3	(-51.5)	-123	(-515)	1
LX-08-0[e]	-44	(-184.1)	-444	(-1841)	1
LX-09-0	+1.82	(+7.61)	+18.2	(+76.1)	1
LX-09-1	+2.004	(+8.38)	+20.04	(+83.8)	1
LX-10-0	-3.14	(-13.1)	-31.4	(-131)	1
LX-11-0	-30.73	(-128.6)	-307.3	(-1286)	1
LX-13 (See XTX-8003)					
LX-14-0	+1.50	(+6.28)	+15.0	(+62.8)	1
LX-15	-4.34	(-18.16)	-43.4	(-181.6)	1
LX-16	-42.71	(-178.7)	-427	(-1787)	1
LX-17-0	-24.04	(-100.6)	-240.4	(-1006)	1
MEN-II	-74.3	(-310.9)	-743	(-3109)	1
Minol-2	-46.43	(-194.3)	-464	(-1943)	1
NC (12.0% N)	-173.7	(-727)	-658	(-2754)	33

Table 5-1. Heats of formation (ΔH_f) for explosives and binders. (Continued)

	ΔH_f				
Explosives	kcal/mol[2]	(kJ/mol)[b]	cal/g	(kJ/kg)[c]	Ref.
NC (13.35% N, min)	-163.0	(-682)	-574	(-2402)	33
NC (14.14% N)	-156.0	(-653)	-525	(-2197)	33
NG	-88.6	(-371)	-390	(-1632)	32
NM	-27.0	(-113)	-442	(-1849)	1
NQ	-22.1	(-92.5)	-212	(-887)	32
Octol 75/25	+2.78	(+11.6)	+27.8	(+116)	1
PBX-9007[e]	+7.13	(+29.8)	+71.3	(+298)	1
PBX-9010[e]	-7.87	(-32.9)	-78.7	(-329)	1
PBX-9011[e]	-4.05	(-17.0)	-40.5	(-170)	1
PBX-9205[e]	+5.81	(+24.30)	+58.1	(+243)	1
PBX-9404-3[e]	+0.08	(+0.331)	+0.8	(+3.31)	1
PBX-9407[e]	+0.81	(+3.39)	+8.1	(+33.9)	1
PBX-9501[e]	+2.28	(+9.5)	+22.8	(+95.4)	1
PBX-9502[e]	-20.83	(-87.2)	-208	(-871.5)	1
PBX-9503[e]	-17.69	(-74.0)	-177	(-740)	1
Pentolite 50/50	-23.9	(-99.9)	-239	(-999.0)	1
PETN	-128.7	(-538.5)	-407	(-1703)	1
Picric acid	-51.3	(-214.6)	-224	(-937)	1
Polystyrene[f]	+18.9	(+79.1)	+181.7	(+760)	
RDX	+14.71	(+61.55)	+66.2	(+277.0)	1
Sylgard 182[f]	-24.9	(-104.2)	335.8	(-1405)	
TACOT	+110.5	(+462.3)	+285	(+1192)	28
TATB	-36.85	(-154.2)	-142.7	(-597.1)	1

Table 5-1. Heats of formation (ΔH_f) for explosives and binders. (Continued)

	ΔH_f				
Explosive	kcal/mol[a]	(kJ/mol)[b]	cal/g	(kJ/kg)[c]	Ref.
Tetryl	+4.67	(+19.5)	+16.3	(+68.2)	1
TNM	+13.0	(+54.4)	+66	(+276)	1
TNT	-16.0	(-66.9)	-70.5	(-295)	32
Viton A	-332.7	(-1392)	-1778	(-7439)	
XTX-8003	-39	(-163)	-390	(-1630)	1
XTX-8004	-1.42	(-5.94)	-14.20	(-59.40)	1

a For mixtures, the molecular weight is arbitrarily taken as 100 g (see Table 4-1).
b One kcal/mol = 4.184 kJ/mol.
c One cal/g = 4.184 kJ/kg.
d Calculated.
e The standard enthalpies of formation of the nonexplosive components of the mixtures were estimated from bond energies.
f Estimated.

5.2. HEATS OF DETONATION

The heat of detonation (ΔH_{det}) refers to the change in enthalpy for the high-order detonation of the explosive and is always a negative value. Initial and final states are taken at 25°C (298 K) and 1 atm (101 kPa) pressure. The experimental values listed in Table 5-2 were determined in a detonation calorimeter under heavy confinement in a gold cylinder. They were found to vary with density, and confinement of the charge.

The maximum heat of detonation is a calculated value for the enthalpy of the reaction

$$\text{Explosive} \longrightarrow \text{Most stable products.}$$

The order chosen for the most stable products of CHNO explosives is H_2O, CO_2, $C_{(s)}$, and N_2. If the explosive contains fluorine and/or chlorine, then the order is HF, HCl, H_2O, CO_2, $C_{(s)}$, and N_2. These values represent the upper limit of the chemical energy obtainable from an explosive. In practice, however, the effective energy developed by a detonating high explosive is always smaller than the assumed thermodynamic maximum energy because 1) the actual shift of the product equilibrium along the adiabat to the freeze-out temperature yields products different from the most stable ones assumed and 2) the actual entropy is higher than for the 25°C (298 K) and 1 atm (101 kPa) pressure stipulated above. The TIGER code was found to give a more realistic estimate of the composition during expansion than did the calculation.

Table 5-2. Heats of detonation ($-\Delta H_{det}$).

	Maximum $(-\Delta H)_{det}$, calculated				Experimental $(-\Delta H)_{det}$				Experimental conditions			
	$H_2O(\ell)$		$H_2O(g)$		$H_2O(\ell)$		$H_2O(g)$		T	Charge diam	Density, ρ	
Explosive	kcal/g	(MJ/kg)[a]	kcal/g	(MJ/kg)[a]	kcal/g	(MJ/kg)[a]	kcal/g	(MJ/kg)[a]	°C (K)	in. (mm)	[g/cm^3 (Mg/m^3)]	Ref.
Amatol 80/20	1.20	(5.02)	0.976	(4.08)	1.02	(4.27)	--	--	--	(12.7)	--	1,4
Baratol[b]	0.74	(3.10)	0.72	(3.01)	--	--	--	--	--	--	--	1
Boracitol[c]	0.40	(1.67)	0.20	(0.84)	--	--	--	--	--	--	--	1
BTF[d]	1.69	(7.07)	1.69	(7.07)	1.41	(5.90)	1.41	(5.90)	25(298)	1/2(12.7)	1.86	1,5
Comp A-3	1.58	(6.61)	1.39	(5.82)	--	--	--	--	--	--	--	1
Comp A-5	1.62	(6.78)	1.61–1.62	(6.74–6.78)	--	--	--	--	--	--	--	1
Comp B, Grade A	1.54	(6.44)	1.40	(5.86)	1.20	(5.02)	--	--	25(298)	(8.47)	1.69	1
Comp B-3	1.54	(6.44)	1.40	(5.86)	1.20	(5.02)	1.12	(4.69)	25(298)	1/3(8.47)	1.69	1
Comp C-3	1.45	(6.07)	1.44	(6.02)	--	--	--	--	--	--	--	1
Comp C-4	1.59	(6.65)	1.40	(5.86)	--	--	--	--	--	--	--	1
Cyclotol 60/40	1.53	(6.40)	1.41	(5.93)	--	--	--	--	--	--	--	1
Cyclotol 75/25	1.57	(6.57)	1.44	(6.02)	--	--	--	--	--	--	--	1
DATB	1.26	(5.27)	1.15	(4.81)	0.98	(4.10)	0.91	(3.81)	25(298)	1/3(8.47)	1.80	1
DIPAM	1.35	(5.65)	1.27	(5.31)	--	--	--	--	--	--	--	1
DNPA	1.06	(4.44)	0.85	(3.57)	--	--	--	--	--	--	--	1
EDNP	1.23	(5.15)	0.94	(3.93)	--	--	--	--	--	--	--	1
EL-506A	1.62	(6.78)	1.38	(5.77)	--	--	--	--	--	--	--	1
EL-506C	1.41	(5.90)	1.12	(4.69)	--	--	--	--	--	--	--	1
FEFO	1.45	(6.07)	1.39	(5.82)	1.28	(5.36)	1.21	(5.06)	25(298)	1/2(12.7)	1.61	6

Table 5-2. Heats of detonation ($-\Delta H_{det}$). (Continued)

	Maximum $(-\Delta H)_{det}$, calculated				Experimental $(-\Delta H)_{det}$				Experimental conditions			
	$H_2O(\ell)$		$H_2O(g)$		$H_2O(\ell)$		$H_2O(g)$		T	Charge diam	Density, ρ	
Explosive	kcal/g	(MJ/kg)[a]	kcal/g	(MJ/kg)[a]	kcal/g	(MJ/kg)[a]	kcal/g	(MJ/kg)[a]	°C (K)	in. (mm)	[g/cm³ (Mg/m³)]	Ref.
HBX-1	1.84	(7.7)	1.8	(7.53)	--	--	--	--	--	--	--	1
HBX-3	2.11	(8.83)	2.11	(8.83)	--	--	--	--	--	--	--	1
HMX	--	--	--	--	1.32	(5.52)	--	--	25(298)	(12.7)	1.20	5
	--	--	--	--	1.3	(5.44)	--	--	25(298)	(12.7)	0.73	5
	1.62	(6.78)	1.48	(6.19)	1.48	(6.19)	1.37	(5.73)	25(298)	1/2(12.7)	1.89	6
HNAB	1.47	(6.15)	1.42	(5.94)	--	--	--	--	--	--	--	1
HNS	1.42	(5.94)	1.36	(5.69)	--	--	--	--	--	--	--	1
Lead azide	0.37	(1.54)	0.37	(1.54)	--	--	--	--	--	--	4.0	1
Lead styphnate	0.46	(1.91)	0.46	(1.91)	--	--	--	--	--	--	2.9	1
LX-01-0	1.72	(7.20)	1.52	(6.36)	--	--	--	--	--	--	--	1
LX-02-1[e]	1.42	(5.94)	1.16	(4.85)	--	--	--	--	--	--	--	1
LX-04-1	1.42	(5.94)	1.31	(5.49)	1.31	(5.49)	1.25	(5.23)	24(297)	1/3(8.47)	1.88	1
LX-07-2	1.49	(6.23)	1.37	(5.73)	--	--	--	--	--	--	--	1
LX-08-0[e]	1.98	(8.27)	1.77	(7.41)	--	--	--	--	--	--	--	1
LX-09	1.60	(6.69)	1.46	(6.11)	--	--	--	--	--	--	--	1
LX-10-0	1.55	(6.49)	1.42	(5.94)	--	--	--	--	--	--	--	1
LX-11-0	1.38	(5.77)	1.28	(5.36)	1.12	(4.69)	1.16	(4.85)	25(298)	1/2(12.7)	1.88	1,5
LX-13 (See XTX-8003)												
LX-14-0	1.58	(6.59)	1.43	(5.95)	--	--	--	--	--	--	--	1
LX-15	1.53	(6.40)	1.34	(5.61)	--	--	--	--	--	--	--	1

Table 5-2. Heats of detonation ($-\Delta H_{det}$). (Continued)

Explosive	Maximum $(-\Delta H)_{det}$, calculated				Experimental $(-\Delta H)_{det}$				Experimental conditions			Ref.
	$H_2O(\ell)$		$H_2O(g)$		$H_2O(\ell)$		$H_2O(g)$		T	Charge diam	Density, ρ	
	kcal/g	(MJ/kg)[a]	kcal/g	(MJ/kg)[a]	kcal/g	(MJ/kg)[a]	kcal/g	(MJ/kg)[a]	°C (K)	in. (mm)	[g/cm^3 (Mg/m^3)]	
LX-16	1.59	(6.65)	1.46	(6.11)	--	--	--	--	--	--	--	1
LX-17-0	1.31	(5.48)	1.02	(4.27)	--	--	--	--	--	--	--	1
MEN-II	1.38	(5.77)	1.05	(4.39)	--	--	--	--	--	--	--	1
Minol-2	2.01	(8.41)	1.86	(7.78)	--	--	--	--	--	--	--	1
NC (12.0% N)	1.16	(4.85)	1.02	(4.27)	--	--	--	--	--	--	--	1
NC (13.35% N, min.)	1.16	(4.85)	1.02	(4.27)	--	--	--	--	--	--	--	1
NC (14.14% N)	1.95	(8.16)	1.81	(7.57)	--	--	--	--	--	--	--	1
NG	1.59	(6.65)	1.48	(6.19)	--	--	--	--	--	--	--	1
NM	1.62	(6.78)	1.36	(5.69)	1.23	(5.15)	1.06	(4.44)	25(298)	1/2(12.7)	1.13	6
NQ	1.06	(4.44)	0.88	(3.68)	--	--	--	--	--	--	--	1
Octol	1.57	(6.57)	1.43	(5.98)	--	--	--	--	--	--	--	1
PBX-9007	1.56	(6.53)	1.39	(5.82)	--	--	--	--	--	--	--	1
PBX-9010	1.47	(6.15)	1.36	(5.69)	--	--	--	--	--	--	--	1
PBX-9011	1.53	(6.40)	1.36	(5.69)	--	--	--	--	--	--	--	1
PBX-9205	1.46	(6.11)	1.41	(5.90)	--	--	--	--	--	--	--	1
PBX-9404-03	1.56	(6.53)	1.42	(5.94)	1.38	(5.77)	1.28	(5.36)	25(298)	1/3(8.47)	1.80	1
PBX-9407	1.60	(6.69)	1.46	(6.11)	--	--	--	--	--	--	--	1
PBX-9501	1.59	(6.65)	1.44	(6.03)	--	--	--	--	--	--	--	1
PBX-9502	1.15	(4.81)	1.05	(4.18)	--	--	--	--	25(298)	--	--	1

Table 5-2. Heats of detonation ($-\Delta H_{det}$). (Continued)

	Maximum $(-\Delta H)_{det}$, calculated				Experimental $(-\Delta H)_{det}$				Experimental conditions			
	$H_2O(\ell)$		$H_2O(g)$		$H_2O(\ell)$		$H_2O(g)$		T	Charge diam	Density, ρ	
Explosive	kcal/g	(MJ/kg)[a]	kcal/g	(MJ/kg)[a]	kcal/g	(MJ/kg)[a]	kcal/g	(MJ/kg)[a]	°C (K)	in. (mm)	[g/cm³ (Mg/m³)]	Ref.
PBX-9503	1.22	(5.10)	1.11	(4.64)	--	--	--	--	25(298)	--	--	1
Pentolite 50/50	1.53	(6.40)	1.40	(5.86)	1.23	(5.15)	1.16	(4.85)	21(294)	1 (25.4)	1.65	7
PETN	1.65	(6.90)	1.51	(6.32)	1.49	(6.23)	1.37	(5.73)	25(298)	1/2(12.7)	1.73	8
	--	--	--	--	1.5	6.29	--	--	--	(6.4)	1.74	1
RDX	1.62	(6.78)	1.48	(6.19)	1.51	(6.32)	1.42	(5.94)	23(296)	1/3(8.47)	1.78	7,9
TACOT	1.41	(5.90)	1.35	(5.64)	0.98	(4.10)	0.96	(4.02)	23(296)	1/3(8.47)	1.74	1
TATB	1.20	(5.02)	1.08	(4.52)	--	--	--	--	--	--	--	1
Tetryl	1.51	(6.32)	1.45	(6.07)	1.14	(4.77)	1.09	(4.56)	21(294)	1 (25.4)	1.71	1
TNM[d,f]	0.55	(2.30)	0.55	(2.30)	--	--	--	--	--	--	--	1
TNT	1.41	(5.90)	1.29	(5.40)	1.09	(4.56)	1.02	(4.27)	25(298)	1/2(12.7)	1.54	6
XTX-8003[e]	1.88	(7.89)	1.69	(7.07)	1.16	(4.85)	1.05	(4.39)	25(298)	1/2(12.7)	1.55	1,5
XTX-8004	1.87	(7.82)	1.67	(6.99)	--	--	--	--	--	--	--	1

a One cal/g = 4.184 kJ/kg.
b $BaCO_3$ is the first product calculated.
c B_2O_3 is the first product calculated.
d Contains little or no hydrogen; therefore, no water is formed, and values for $H_2O(\ell)$ and $H_2O(g)$ are identical.
e SiO_2 is the first product calculated.
f A very small percentage of CH_2 impurity raises these values markedly.

5.3. COMPATIBILITY

Many materials have been tested for compatibility with various HEs; those listed or mentioned in this section are commonly used at the LLNL facility for explosive testing. In Tables 5-3 and 5-4, which list adhesives and fillers, those materials rated "A" have been evaluated extensively; those rated "B" have been screened for gross incompatibility only. If these materials are used as they are supplied (i.e., in the prepackaged catalyst/resin system), they are satisfactory for use as indicated. It is understood that the adhesives are used in minimal amounts, mixed according to supplier's instructions, and used only for limited times (i.e., from two to three months during environmental testing).

The results of our compatibility tests are valid only for the specific batch or lot of HE and adhesive tested.[10] For different HEs and subsequent lots of adhesive, even from the same supplier, the reactivity and compatibility tests must be repeated. The supplier may change or "improve" the material without notice; this could render the material incompatible.

This compilation should not be regarded as complete; many other materials have been evaluated, but are not included here because they are not commonly used. Table 5-5 lists adhesive tapes found compatible with various HEs; any other tapes should be tested before use.

Table 5-3. Adhesives: Chemical reactivity and compatibility with HEs.[a]

Adhesive	High explosive																
	Baratol	Comp B	EL-506	LX-04	LX-07	LX-10	LX-14	LX-17	PBX-9007	PBX-9010	PBX-9205	PBX-9404	PBX-9407	Tetryl	TNT	XTX-8003/LX-13	XTX-8004
Adiprene LW520/MDA	A	A	-	A	A	A	A	A	-	A	A	A	-	A	A	-	-
Adiprene L-315/Polyol	A	A	-	A	A	A	A	A	-	A	A	A	-	A	A	-	-
Aerobond 2017	-	-	-	A	A	A	-	-	-	-	-	A	-	-	-	-	-
Eastman 910	A	A	A	A	A	A	A	A	-	A	A	A	-	A	A	-	-
Epoxies[b]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Explostix 473	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-
Halthane 73-14[c]	A	A	-	A	A	A	A	A	-	A	A	A	-	A	A	-	-
Halthane 73-15[c]	A	A	-	A	A	A	A	A	-	A	A	A	-	A	A	-	-
Halthane 73-18[c]	A	A	-	A	A	A	A	A	-	A	A	A	-	A	A	-	-
Halthane 73-19[c]	A	A	-	A	A	A	A	A	-	A	A	A	-	A	A	-	-
Halthane 87-1[c]	A	A	-	A	A	A	A	A	-	A	A	A	-	A	A	-	-
Halthane 88-2[c]	A	A	-	A	A	A	A	A	-	A	A	A	-	A	A	-	-
Laminac 4116	-	-	A	A	A	A	-	-	-	-	-	A	-	-	-	-	-
3M #465	-	-	-	A	A	A	-	-	A	-	-	-	A	-	-	-	-
3M #466	-	-	-	A	A	A	-	-	A	-	-	-	A	-	-	-	-
3M #Y9146	-	-	-	A	A	A	-	-	A	-	-	-	A	-	-	-	-
Quik-Stick Spray	-	-	B	-	-	-	-	-	-	-	-	-	-	-	-	B	B

a A, compatible; OK for long-term storage.
B, compatible; OK for short-term storage (less than 30 days).
-, compatibility has not been checked.

b BIPAX-2902, EPY-150, and Hysol epoxy patch kit are epoxies certified only for bonding strain gages to LX-04, LX-07, LX-10, LX-17, and PBX-9404.

c Compositions, mixing ratios, and characterization of the Halthane adhesives are given in H. G. Hammon, L. P. Althouse, and D. M. Hoffman, Development of Halthane Adhesives for Phase 3 Weapons: Summary Report, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-52943 (1980).

Table 5-4. Fillers and coatings: Chemical reactivity and compatibility.[a]

	High explosive							
Filler or Coating	LX-04	LX-07	LX-10	LX-14	LX-17	PBX-9010	PBX-9205	PBX-9404
APC 1[b,c]	A	A	A	A	A	A	A	A
APC 2.5[b,c]	A	A	A	A	A	A	A	A
APC 5[b,c]	A	A	A	A	A	A	A	A
APC 300[b,c,d]	A	A	A	A	A	A	A	A
DP 4817 conductive Ag[d]	A	A	A	-	A	B	-	A
FDA 2 Red	A	A	A	A	-	A	A	A
FDA 3 Green	A	A	A	A	-	A	A	A
GE RTV 632[b,e,f]	A	A	A	A	A	A	A	A
Silastic RTV 732[f]	A	A	A	A	A	A	A	A
Silastic RTV 891[f]	A	A	A	A	A	A	A	A
Sylgard 184[b]	A	A	A	A	A	A	A	A
Sylgard 186[b]	A	A	A	A	A	A	A	A

[a] A, compatible; OK for long-term storage.
B, compatible; OK for short-term storage (less than 30 days).
-, compatibility has not been checked.

[b] These materials cure under the influence of a platinum catalyst. They are easily poisoned by a number of materials, and should therefore be mixed only in clean containers.

[c] The APC (Addition Potting Compound) formulations were developed at LLNL and at PX. See W. E. Cady, Development of Alternate Silicone Potting Compounds, Vols. 1-9, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-52434 (1978-1981).

[d] DP means E. I. DuPont de Nemours and Co., Inc.

[e] This formulation of a nonflowing material can be used where a material of very high viscosity is needed.

[f] RTV means Room-Temperature Vulcanizing.

Table 5-5. Adhesive tapes compatible with HEs.[a]

Manufacturer	Trade name	Number	Color
3M	Scotch Brand Electrical Tape	#33	Black
3M	Scotch Brand Mylar	#56	Yellow
3M	Scotch Brand Electrical	#57	Yellow
3M	Scotch Brand Masking	#232	Tan
3M	Scotch Brand Photo Tape	#235	Black
3M	Scotch Brand Double Sided Masking	#400	Tan
3M	Scotch Brand Tape	#420	Gray
3M	Scotch Brand Double Sided Masking	#465	Tan
3M	Scotch Brand Double Sided Masking	#466	Tan
3M	Scotch Brand Plastic	#471	Yellow
3M	Scotch Brand Plastic	#471	Red
3M	Scotch Brand Plastic	#471	White
3M	Scotch Brand Cellophane Tape	#600	Clear
3M	Scotch Brand Cellophane Tape	#850	Clear
3M	Scotch Brand Magic Mending	#810	Clear
3M	Scotch Filament Tape	#880	Pearl
3M	Scotch Brand Double Sided Masking	#Y9146	Tan
Behr-Manning	Bear Tape	#4/1	Tan
Hampton Manufacturing Company	Blue Cross Tape	--	Yellow
Mystik Tape, Inc.	Mystic Tape	#5803	Black
Okonite Company	High Voltage Rubber Tape	---	Brown
Permacel	Permacel	#29	Black
Permacel	Permacel	#32	Red

Table 5-5. Adhesive tapes compatible with HEs.[a] (Continued)

Manufacturer	Trade name	Number	Color
Permacel	Permacel Cellophane Tape	--	Clear
Saunders Engineering Corporation	Teflon Tape Teflon Tape Teflon Tape	#S15 #S16 #S18	Blue/brown
Technical Tape Corporation	Tuck Tape	--	Yellow
Technical Tape Corporation	Tuck Tape	--	Black

a Any tape not listed should be tested before use.

5.4. SOLUBILITY

Qualitative solubilities for explosives and related materials are given in Tables 5-6 and 5-7. Because the degree of solubility of a substance depends on concentration and temperature of the solvent, the reader should consult the references to determine the experimental conditions.

Table 5-6. Qualitative solubilities of pure explosives.[a]

	Explosive																							
References:	11,30	11,12	13					13,14,30		13	15	13	13 30	16 30		13	30	17,30	13,30	18	18-20	13,30		30
Solvent	AN	AP	BTF	DATB	DIPAM	DNPA	EDNP	EXPL-D	FEFO	HMX	HNAB	HNS	NC	NG	NM	NQ	PETN	Picric acid	RDX	TACOT	TATB	Tetryl	TNM	TNT
Acetone	i	sl	s	sl	sl	s	s	–	s	sl	s	i	s	s	–	i	s	s	s	–	i	s	–	s
Benzene	–	–	s	i	–	–	–	s_	–	–	sl	–	–	s	–	i	sl	s	i	–	i	s	s	s
Butyrolactone	–	–	–	sl	–	–	–	–	–	b	s	sl	–	–	–	–	–	–	–	–	–	–	–	–
Carbon disulfide	–	–	–	i	–	–	–	–	–	i	–	–	–	sl	–	i	i	sl	i	–	i	i	–	sl
Carbon tetrachloride	–	–	i	i	–	–	s	i	i	i	i	–	i	sl	–	i	i	–	i	–	i	i	–	sl
Chloroform	–	–	–	–	sl	–	s	–	s	i	sl	–	i	s	–	i	i	s	i	i	i	sl	–	s
DMFA	s	s	s	sl	s	–	s	s	s	b	s	sl	–	–	s	s	s	–	s	sl	i	s	–	s
DMSO	–	–	s	sl	s	–	s	–	s	b	s	sl	–	–	s	–	s	–	s	s	i	–	–	–
Ethanol	sl	sl	s	i	–	–	s	s	s	–	sl	–	sl	s	s	sl	i	s	sl	i	i	sl	s	sl
Ethyl acetate	i	i	s	–	–	–	s	sl	s	–	s	–	s	s	–	i	s	s	i	–	i	s	–	s
Ethyl ether	i	i	s	–	–	–	s	sl	s	i	i	–	i	s	s	i	sl	sl	i	–	i	sl	s	sl
N-methyl-pyrrolidone	–	–	–	sl	–	–	–	–	–	b	s	sl	–	–	–	–	–	–	s	–	i	–	–	–
Nitric acid	s	–	–	–	s	–	–	–	–	–	–	–	–	s	–	sl	–	–	–	sl	–	s	–	s
Pyridine	sl	–	s	–	–	–	s	–	s	sl	s	–	–	s	–	–	s	–	sl	sl	i	–	–	s
Sulfuric acid	–	–	–	–	–	–	–	–	–	–	sl	–	–	s	–	s	–	sl	–	–	s	–	–	s
Water	s	s	i	i	–	–	i	s	i	i	sl	–	i	sl	s	i	i	sl	i	i	i	i	sl	i

[a] Solubilities are expressed as follows, in terms of weight of substance dissolved at room temperature per 100 ml of solvent: i = insoluble (<0.1 g), sl = slightly soluble (0.1 to 5 g), s = soluble (>5 g).
[b] Solvate.

Table 5-7. Qualitative solubilities of additives and binders.[a]

References:	21		22	23	24	25	26	27		
	Additive or binder									
Solvent	BDNPA-F	Cab-O-Sil	CEF	DOP	Estane 5702-F1	FPC 461	Kel-F	Poly-styrene	Sylgard 182	Viton A
Acetone	–	i	–	–	s	–	s	–	–	s
Benzene	s	i	s	–	–	–	–	s	–	–
Dichloroethane	–	i	–	–	s	–	–	–	–	–
DMFA	–	i	–	–	s	–	–	–	–	–
DMSO	–	i	–	–	s	–	–	–	–	–
Gasoline	–	i	–	s	–	s	–	–	–	–
Glycerine	–	i	–	i	–	–	–	–	–	–
MEK	–	i	s	–	s	s	s	–	–	s
MIBK	–	i	s	–	s	–	s	–	–	s
THF	–	i	–	–	s	–	s	–	–	s
Toluene	s	i	s	–	–	s	i	s	–	–
Water	i	i	i	i	–	–	–	–	–	–
Xylene	–	i	s	–	–	s	–	–	–	–

[a] Solubilities are expressed as follows, in terms of weight of substance dissolved at room temperature per 100 ml of solvent: i = insoluble (<0.1 g), sl = slightly soluble (0.1 to 5 g), s = soluble (>5 g).

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6. THERMAL PROPERTIES

This section contains tables and information on thermal conductivity (λ), coefficient of thermal expansion (CTE), specific heat (Cp), glass transition point (T_g), and thermal stability. Thermal conductivity λ increases with increasing HMX content whereas the CTE decreases.

6.1. THERMAL CONDUCTIVITY

Measurements of thermal conductivity (λ), made on an apparatus similar to that used at the National Bureau of Standards,[18] are included in Table 6-1. Thermal conductivities as a function of temperature are given in Fig. 6-1 for PBXs; the straight lines represent the best fits of the data. The thermal conductivity data shown in Fig. 6-2 as a function of HMX content indicate the range of properties available with HMX/Viton explosives.

Table 6-1. Thermal conductivities (λ) of explosives and binders.

		Thermal conductivity, λ			Temperature		
Material	Density, ρ [g/cm^3 (Mg/m^3)]	Btu/ hr-ft-°F	10^{-4} cal/ cm-sec-°C	(W/m-K)[a]	°C	(K)	Ref.
AN			2.9- 3.9	(0.121- 0.163)			1
AP[b]			12.0	(0.502)	50	(323)	2
			11.6	(0.485)	100	(373)	2
			11.0	(0.460)	150	(423)	2
			10.3	(0.431)	200	(473)	2
			9.6	(0.402)	240	(523)	2
Baratol			11.84	(0.495)	18-75	(291-348)	
Comp B	1.70		5.4	(0.226)	25	(298)	3
Comp B-3			6.27	(0.262)	18-75	(291-348)	
	1.730		5.23	(0.219)	46	(319)	4
Comp C-4			6.22	(0.260)			
Cyclotol 75/25	1.760		5.41	(0.227)	46	(319)	4
DATB	1.834		6.00	(0.251)			

Table 6-1. Thermal conductivities (λ) of explosives and binders. (Continued)

Material	Density, ρ [g/cm³ (Mg/m³)]	Thermal conductivity, λ Btu/hr-ft-°F	10^{-4} cal/cm-sec-°C	(W/m-K)[a]	Temperature °C	(K)	Ref.
Estane 5702				(0.146)			
Estane 5703	1.18		3.53	(0.148)	41.4	(314.4)	5
H-6			11.01	(0.460)	35	(308)	1
HBX-1			9.7	(0.406)	35	(308)	1
HBX-3			17.0	(0.711)	35	(308)	1
HMX			12.2-13.3	(0.511-0.556)	RT		6
	1.91		9.83	(0.418)			7
			10.13	(0.424)			
HNS-I	1.646		2.04	(0.085)	20	(293)	8
HNS-II	1.646		1.91	(0.080)	20	(293)	8
Kel-F 800	1.900		1.26	(0.053)	41.4	(314.4)	5
Lead azide	4.1		4.2	(0.176)			9
	3.6		6.61	(0.277	72-130	(345-403)	62
(powder)	0.88		1.55	(0.065)			9
LX-04	1.87		10.7	(0.448)	20	(293)	6
LX-07	1.87		12.0	(0.502)	20	(293)	6
LX-09	1.84		12.3	(0.515)	20	(293)	6
LX-10	1.86		12.3	(0.515)	20	(293)	6
LX-11 (est.)		0.21		(0.363)	21.1	(294)	-
LX-14-0	1.83		10.42	(0.439)	20	(293)	10
LX-17-0	1.88		19.1	(0.799)	20	(293)	6
	1.89		12.1	(0.504)	40	(313)	15
Minol-2	1.74		16.5	(0.6904)			11
NC (12.7% N)			5.5	(0.230)			-
	1.5		2.15	(0.09)			9
NQ[c]	1.651		10.14	(0.424)	41.3	(314.3)	4
NQ[d]	1.689		9.85	(0.412)	41.3	(314.3)	4
PBX-9010	1.875		5.14	(0.215)	48.8	(321.8)	4
PBX-9011		0.25		(0.432)	21.1	(294)	-
	1.772		9.08	(0.380)	43.4	(316)	4

Table 6-1. Thermal conductivities (λ) of explosives and binders. (Continued)

Material	Density, ρ [g/cm³ (Mg/m³)]	Thermal conductivity, λ Btu/hr-ft-°F	10^{-4} cal/cm-sec-°C	(W/m-K)[a]	Temperature °C	(K)	Ref.
PBX-9404		0.25		(0.432)	21.1	(294)	-
	1.845		9.2	(0.385)	46.2	(319)	4
PBX-9501	1.847		10.84	(0.454)	55	(328)	4
PBX-9502	1.893		13.2	(0.552)	38	(311)	4
Picric acid	1.60		2.4	(0.100)			9
Polystyrene			2.51	(0.105)	0	(273)	12
			2.78	(0.116)	50	(323)	12
			3.06	(0.128)	100	(373)	12
RDX	1.806		2.53	(0.106)			7
	1.66		1.75	(0.073)	20	(293)	13
	1.81		2.53	(0.106)			2
Sylgard 182			3.5 cured	(0.146)			14
TATB	1.938		13	(0.544)			7
	1.891		12.8	(0.536)	38	(311)	4
	1.841		11.2	(0.469)			15
	1.858		11.0	(0.460)			15
	1.827		10.7	(0.448)			15
	1.826		10.4	(0.435)			15
Tetryl	1.53		2.48	(0.104)			64
	1.53		6.83	(0.286)			63
(pressed)	1.7		2.3	(0.096)			9
(powder)	0.767		2.0	(0.084)			9
TNT	1.654		6.22	(0.260)	18-45	(291-318)	7
	1.63		7.1	(0.297)	90-100	(363-373)	3
(pressed)	1.56		4.8	(0.201)			9
(powder)	0.846		3.5	(0.146)			9
	1.65			(0.13-0.26)			16
Viton A	1.815		5.4	(0.226)			17
XTX-8003	1.54		3.42	(0.143)			10
XTX-8004	1.540		3.42	(0.143)	40	(313)	4

[a] One cal/cm-sec-°C = 4.184 x 10^2 W/m-K; 1 Btu/hr-ft-°F = 0.004 cal/cm-sec-°C = 1.73 W/m-K. Where measurements were made in both British and metric units, only the British data were converted.
[b] 43 to 61-μm particle size.
[c] Low bulk density.
[d] High bulk density.

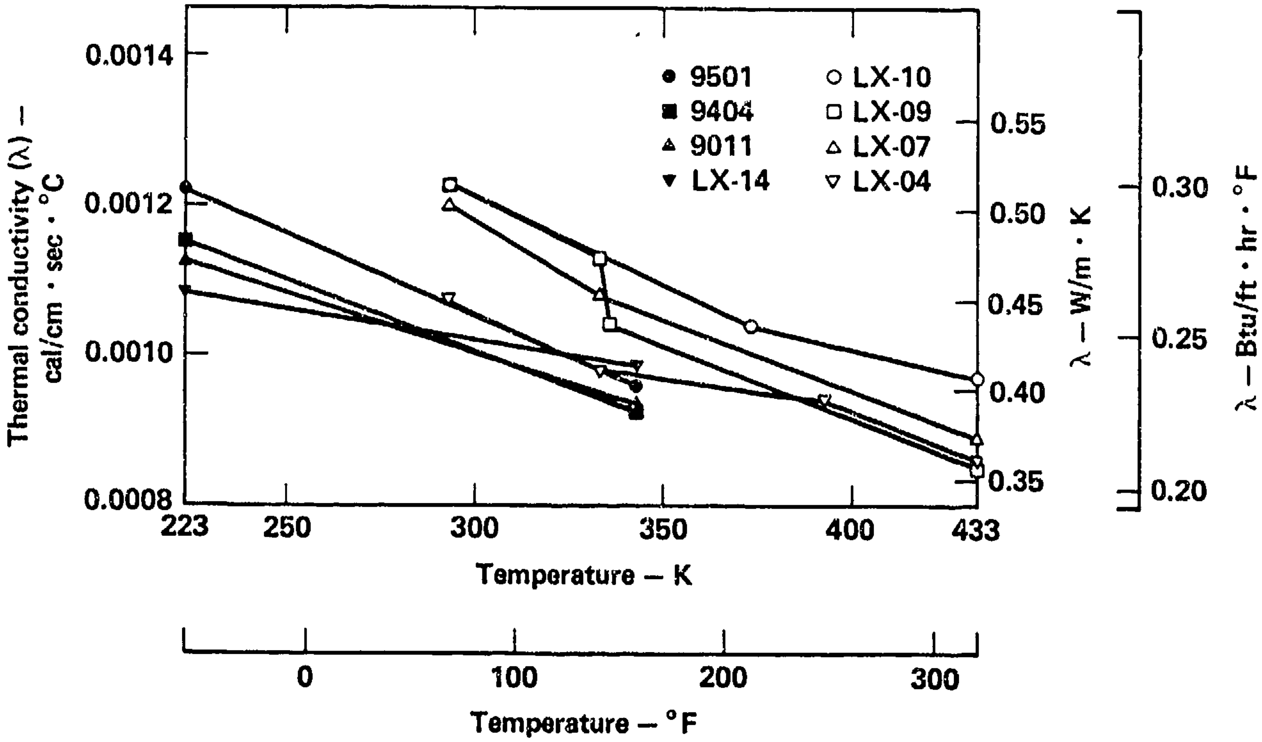


Fig. 6-1. Thermal conductivities of PBXs as a function of temperature.[6,18]

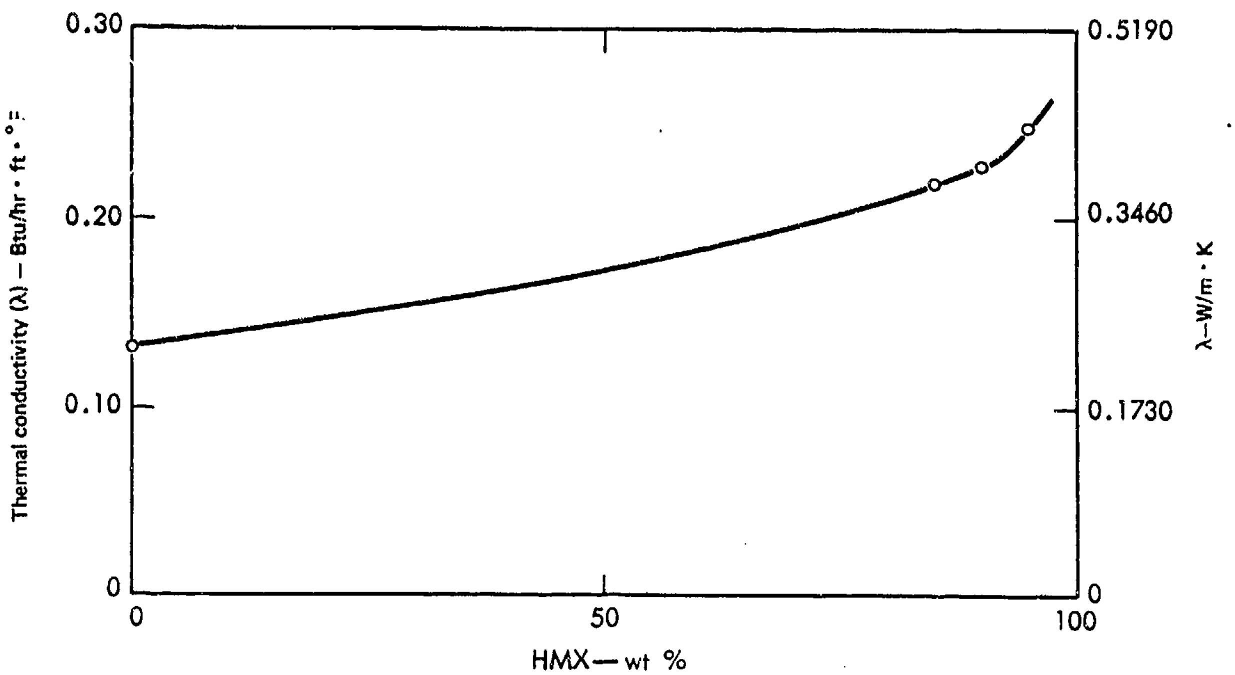


Fig. 6-2. Thermal conductivity (λ) vs wt% HMX for HMX/Viton systems at 70°F (294 K).[18] The conversion factors are 1 Btu/hr-ft-°F = 1.73 W/m-K and 1 cal/cm-sec-°C = 4.184 x 10^2 W/m-K.

6.2. THERMAL EXPANSION

Thermal expansion data were obtained using bulk mercury dilatometers or a linear expansion apparatus; the two methods produce comparable results.[18] Figure 6-3 shows CTE as a function of HMX content for HMX/Viton systems. Table 6-2 lists the measured linear (α) and cubic (β) expansion coefficients of explosives and binders along with their glass transition temperatures and pressed densities. The cubic expansion coefficients (β) can be calculated for isotropic materials as $\beta = 3\alpha$.

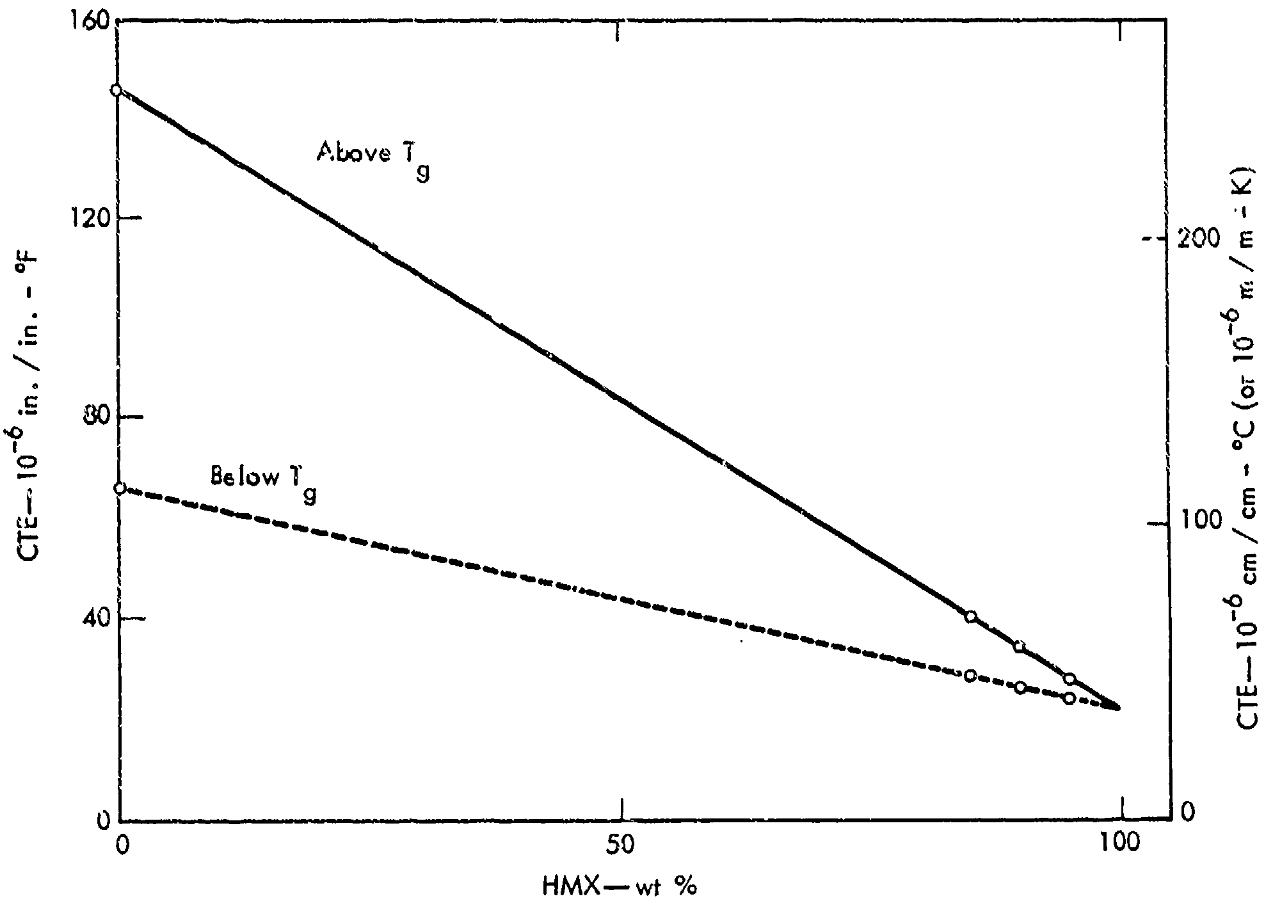


Fig. 6-3. Coefficients of thermal expansion (CTE) vs wt% HMX for HMX/Viton systems. The conversion factors are 1 in./in.-°F = 1.8 cm/cm-°C = 1.8 m/m-K.

Table 6-2. Coefficients of thermal expansion (CTE), glass transition temperatures (T_g), and pressed densities (ρ) for explosives and binders.

Material	Linear CTE (α)[a] μin./in.-°F	Linear CTE (α)[a] [μcm/cm-°C (μm/m-K)]	T °F or °C	T (K)	Ref.	Cubic CTE (β)[a] [μcm/cm-°C (μm/m-K)]	T °C (K)	T_g °F or °C	T_g (K)	Pressed density [g/cm^3 (Mg/m^3)]	Ref.
AN						982	20 (293)				
AP		~40	20°C	(293)	20						
Baratol		33+0.26T	-40 to 60°C	(233-333)	18						
Boracitol		46.7	0 to 60°C	(273-333)	18						
CEF						840					22
Comp A-3		71.7	-20 to 20°C	(253-293)	1						
Comp B		54.6	6 to 25°C	(279-298)	18						
		97.5	27 to 63°C	(300-336)	18						
DATB		32-46	-20°C	(253)	18						
		52-66	85°C	(358)	18						
DOP		74	10 to 40°C	(283-313)	21						
Estane 5702-F1					19	600		-31°C	(242)		18,21
Estane 5703		245	20-44°C		23	~600					23
H-6	83	(149)	35°C	(308)	1						
HBX-1	95	(171)	35°C	(308)	1						
HBX-3	83	(149)	35°C	(308)	1						
HMX		50.4	-53.9 to 73.9°C	(219-347)	22	162.5	-30 to 70 (243-343)	None			18,22
	22.0		-65 to 165°F	(219-347)	18						
HNAB		80			24						
HNS		92			24						
Kel-F 800			60-105	<T_g	25			30.2-31.3	(303.2-304.3)		25
			300-1600	>T_g							
		304	25 to 54°C	(298-327)	23	~700					23
Kel-F 3700						~700		-51°C	(222)		23

Table 6-2. Coefficients of thermal expansion (CTE), glass transition temperatures (T_g), and pressed densities (ρ) for explosives and binders. (Continued)

Material	Linear CTE (α)[a] µin./in.-°F	Linear CTE (α)[a] [µcm/cm-°C (µm/m-K)]	T °F or °C	T (K)	Ref.	Cubic CTE (β)[a] [µcm/cm-°C (µm/m-K)]	T °C (K)	T_g °F or °C	T_g (K)	Pressed density [g/cm³ (Mg/m³)]	Ref.
Lead azide											
a axis		76.9	13°C	(286)	26						
b axis		3.4									
c axis		18.3									
LX-02		128.7	-20 to 50°C	(244-253)	18	385	-30 to 70 (243-343)	None above -4°F	(253)		18,22
LX-04	28.5	(51.3)	-65 to -18°F	(219-245)	18	228.2	-30 to 70 (243-343)	-18°F	(245)	1.860-1.870	18,22
	39.5	(71.1)	-18 to 165°F	(245-347)	18						
LX-07	26.7	(48)	-65 to -18°F	(219-245)	18	182.9	-30 to 70 (243-343)	-18°F	(245)	1.860-1.870	18,22
	34.8	(63)	-18 to 165°F	(245-347)	18						
LX-08	104.5	(188)			18	565					22
LX-09	27.1	(48.8)	-65 to -20°F	(219-244)	18			-20°F	(244)	1.835-1.845	18
	31.0	(55.8)	-20 to 165°F	(244-347)	18						
LX-10	24.8	(44.6)	-65 to 0°F	(219-255)	18			-18°F	(245)		18
	26.2	(47.0)	0 to 165°F	(255-347)	18						
LX-11	31 est.	(56)	-65 to -10°F	(219-249)	18			-18°F	(245)		18
	46 est.	(83)	10 to 165°F	(261-347)	18						
LX-13 (See XTX-8003)											
LX-14	27	(48.5)	<30°F	(<239)	19						
	31	(55.8)	>30°F	(>239)	19						
	25.4	(45.7)	-65 to -30°F	(219-239)	10						
	31.6	(56.9)	-30 to 165°F	(239-347)	10						
LX-17-0		40.4	-54 to 15°C	(219-288)	54						
		60.2	15 to 74°C	(288-347)	54						
		46	-73°C	(200)	27						
		57	20°C	(293)	65						
NC (12.7% N)		80-120		(219-239)	18						
PBX-9010		66			18						
PBX-9011	28.7	(51.7)	-65 to -40°F	(219-233)	18			-35°F	(236)		18
	37.3	(67.1)	-30 to 165°F	(243-347)	18						

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Table 6-2. Coefficients of thermal expansion (CTE), glass transition temperatures (T_g), and pressed densities (ρ) for explosives and binders. (Continued)

Material	Linear CTE (α)[a] µin./in.-°F	Linear CTE (α)[a] [µcm/cm-°C (µm/m-K)]	T °F or °C	T (K)	Ref.	Cubic CTE (β)[a] [µcm/cm-°C (µm/m-K)]	Cubic T °C (K)	T_g °F or °C	T_g (K)	Pressed density [g/cm^3 (Mg/m^3)]	Ref.
PBX-9205		54	-73°C	(200)	27						
PBX-9404	28.1	(50.6)	-65 to -30°F	(219-239)	18			-29°F	(239)	1.828-1.842	18
	32.2	(58.0)	-10 to 165°F	(250-347)	18						
PBX-9501	30.6	(55.1)	-80 to 160°F	(211-344)	18						
PBX-9502		44	-73°C	(200)	27						
PETN	46.1	(83.0)			22	249.2	-30 to 70 (243-343)	None			18,22
		76.5	20°C	(293)	28	232	(293)				22
		89.9	90°C	(363)	29	297	(363)				22
Polystyrene		60-80	<100°C	(<373)	12	170-210	<100°C (<373)	100°C	(373)		12
						510-600	>100 (>373)				12
RDX		63.6	20°C	(293)	28	191	20 (293)				28
Sylgard 182	180.0	(324)	-65 to 165°F	(219-347)	18						
TATB		54	-73°C	(200)	27						
(cryst., triclinic)		101	-59 to 104°C	(214-377)	29						
(cryst., monoclinic)		95	-57 to 107°C	(216-380)	29						
(powder)		50	-50 to 70°C	(223-343)	29					1.866	
TNT		50.0+0.078T			Below m.p.		18				
a axis		~39		(280)	30	~180	(293)				30
b axis		~32		(280)	30						
c axis		~96		(280)	30						
Viton A	65.0	(117)	<-6°F	(<252)	18	~450	<-20 (253)	-27°C	(246)	1.819	18,22
	145.2	(254.8)	-6 to 165°F	(252-347)	18	728	-20 to 70 (253-343)				18,22
XTX-8003	68.8	(123.8)	-22 to 158°F	(243-343)	18	413.7	-53.9 to 73.9 (219-236)			1.544	22
	77	(139)	75 to 150°F	(297-339)	18						
XTX-8004		231									

[a] One µin./in.-°F = 1.8 µcm/cm-°C = 1.8 µm/m-K.

6.3. SPECIFIC HEAT

Specific heat (C_p) for the plastic components of PBXs were estimated at LLNL using the Kopp-Joule rule. Specific heat for the PBX was then calculated by applying the appropriate weight fractions to the specific heats of the components. The estimated values of C_p listed in Table 6-3 are believed accurate to ±5%. Values for C_p at temperatures other than 20°C (293 K) for HMX-containing PBXs can be estimated by the formula

$$C_p(T) = C_p(T_0)\left(\frac{C_p(T)\ \text{HMX}}{C_p(T_0)\ \text{HMX}}\right),$$

where $C_p(T)$ is the specific heat at a temperature other than 20°C (293 K) and $C_p(T_0)$ is the specific heat at 20°C (293 K). Values for C_p at temperatures other than 20°C (293 K) for RDX-containing PBXs can be similarly estimated by substituting RDX values into the formula.

Specific heats were also determined by differential scanning calorimetry. The specific heats of HMX, TATB and RDX as a function of temperature are shown in Fig. 6-4 and for HMX/binder formulations in Fig. 6-5.[33,34,46]

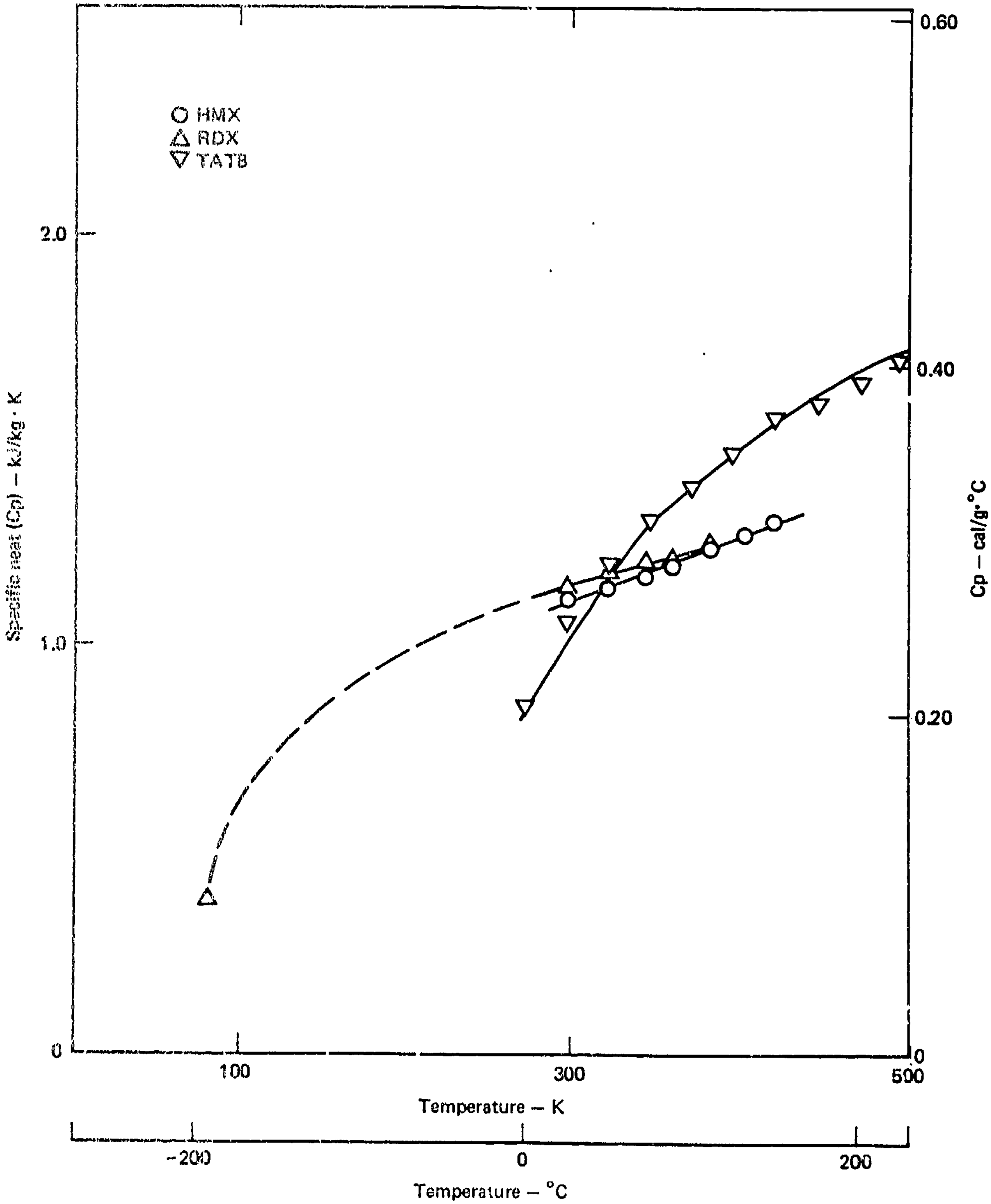


Fig. 6-4. Specific heats (C_p) of HMX, RDX, and TATB determined by differential scanning calorimetry and shown as a function of temperature.[33,34]

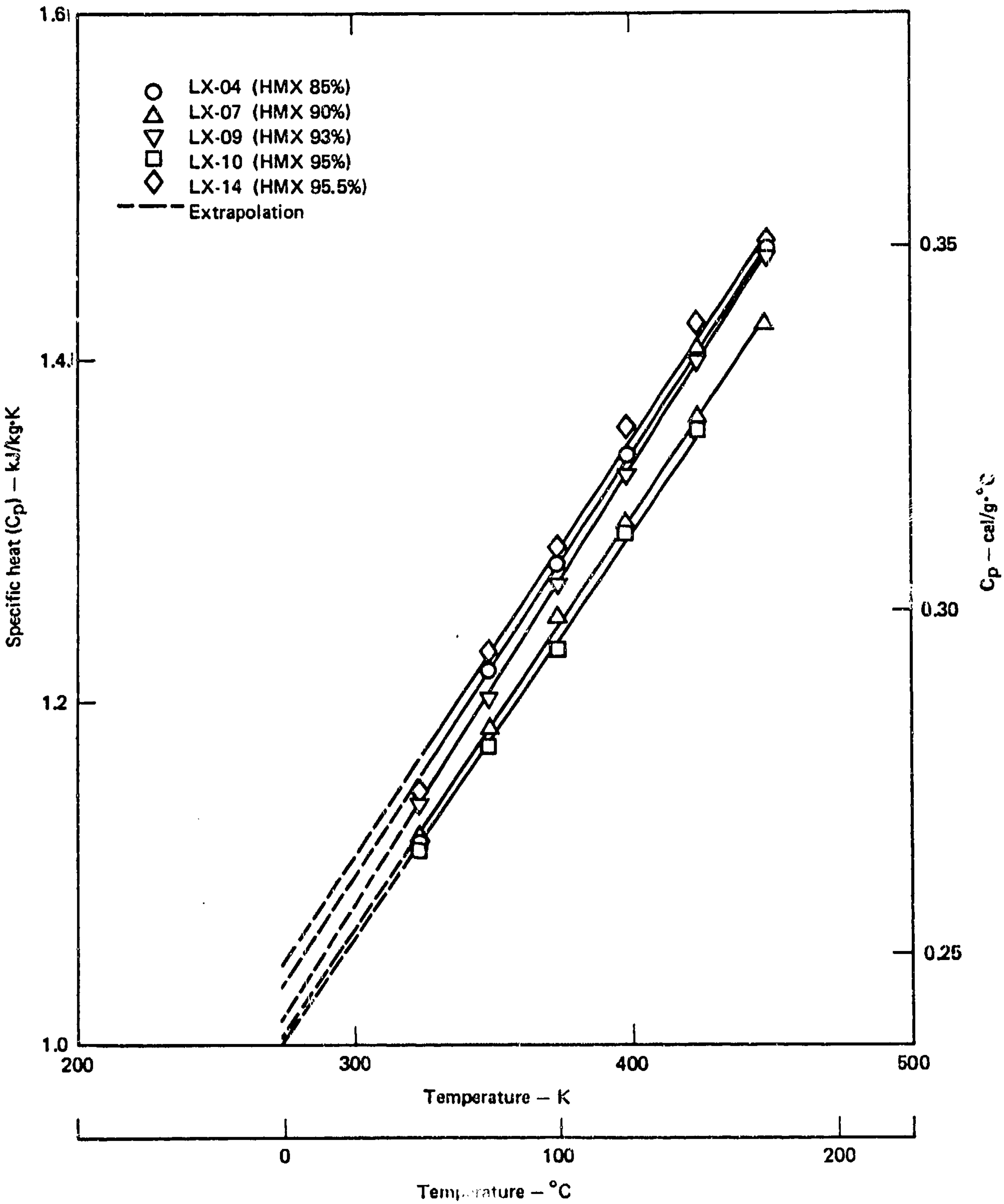


Fig. 6-5. Specific heats (C_p) of HMX/binder formulations determined by differential scanning calorimetry and shown as a function of temperature.[46]

Table 6-3. Specific heats (C_p).

Explosive	C_p(est.) at 20°C (293 K)[31] cal/g-°C[a]	C_p(est.) at 20°C (293 K)[31] (kJ/kg-K)[b]	C_p, experimental cal/g-°C[a]	C_p, experimental (kJ/kg-K)[b]	Ref.
AN	0.4 at 0°C	(1.67 at 273 K)	--	--	1
AP	0.31 at 15-240°C	(1.29 at 288-513 K)	--	--	32
	0.37 at >240°C	(1.53 at >513 K)	--	--	32
Baratol	--	--	0.157 at 30°C	(0.657 at 303 K)	33
	--	--	0.201 at 50°C	(0.841 at 323 K)	33
	--	--	0.403 at 70°C	(1.686 at 343 K)	33
	--	--	0.192 at 83-100°C	(0.803 at 356-373 K)	33
BTF	0.3 est.	(1.25)	--	--	34
Comp B	--	--	0.27 at 25°C	(1.130 at 298 K)	3
Comp B-3	--	--	0.299 at 30°C	(1.251 at 303 K)	35
	--	--	0.307 at 50°C	(1.284 at 323 K)	35
	--	--	0.325 at 70°C	(1.359 at 343 K)	35
	--	--	0.333 at 83-100°C	(1.393 at 356-373 K)	35
	--	--	$0.234+(10.3\times10^{-4})T$ at 7-67°C		4
	--	--	$0.137+(20.9\times10^{-4})T$ at 97-157°C	--	4
Cyclotol 75/25	--	--	0.254 at 25°C	(1.063 at 298 K)	1
DATB	--	--	0.23	(0.962)	34
	--	--	$0.20+(1.11\times10^{-3}T)-(1.81\times10^{-6})T^2$ at 47-200°C	--	35

Table 6-3. Specific heats (C_p). (Continued)

	C_p(est.) at 20°C (293 K)[31]		C_p, experimental		
Explosive	cal/g-°C[a]	(kJ/kg-K)[b]	cal/g-°C[a]	(kJ/kg-K)[b]	Ref.
DIPAM	--	--	0.25	(1.05)	34
	--	--	$0.235+(6.2\times10^{-4})T - (4.75\times10^{-7})T^2$ at 47-227°C	--	35
DOP	--	--	∿0.57 at 50-150°C	(∿2.385 at 323-423 K)	21
Estane 5702	--	--	--	(1.48 below T_g)	23
	--	--	--	(1.71 above T_g)	23
Estane 5703	--	--	0.354 below T_g	(1.56 below T_g) 37-60°C	23
	--	--	0.409 above T_g	(1.68 above T_g) 75-200°C	23
Explosive D	--	--	$0.287+(6.8\times10^{-4})T$ at 37-207°C	--	4
FEFO	0.25 at -73°C	(1.05 at 200 K)	--	--	36
	0.36 at 25°C	(1.51 at 298 K)	--	--	36
	0.47 at 127°C	(1.97 at 400 K)	--	--	36
H-6	--	--	0.269 at 30°C	(1.126 at 303 K)	1
HBX-1	0.24 at 5°C	(1.004 at 278 K)	0.249 at 30°C	(1.042 at 303 K)	37
HBX-3	--	--	0.254 at 30°C	(1.063 at 303 K)	1

Table 6-3. Specific heats (C_p). (Continued)

Explosive	C_p(est.) at 20°C (293 K)[31] cal/g-°C[a]	C_p(est.) at 20°C (293 K)[31] (kJ/kg-K)[b]	C_p, experimental cal/g-°C[a]	C_p, experimental (kJ/kg-K)[b]	Ref.
HMX	--	--	$0.231+(5.5\times10^{-4})T$ at 37-167°C	--	4
	--	--	$0.230+(6.36\times10^{-4})T$ up to 160°C	--	38
	--	--	$0.228+(8.624\times10^{-4})T$ $-1.864\times10^{-6}T^2$	--	7
HNAB	0.3	(1.25)	--	--	35
HNS-I	--	--	0.235 at 20°C	(0.983 at 293 K)	8
HNS-II	--	--	0.225 at 20°C	(0.941 at 293 K)	8
HNS	--	--	0.23	(0.962)	
	--	--	$0.201+(1.27\times10^{-3})T$ $-(2.39\times10^{-6})T^2$ at 47-220°C	--	35
	0.40	(1.67)	--	--	39
Kel-F 800	--	--	0.239 below Tg (37-90°C)	(1.004 below Tg) 310-363K	23
Lead azide	--	--	0.09	(0.377)	9
			0.107 at 100°C	(0.448 at 373 K)	62
LX-02	0.29	(1.21)	--	--	
LX-08	0.28	(1.17)	--	--	
LX-11	0.31	(1.26)	--	--	
LX-13	0.27	(1.13)	--	--	

Table 6-3. Specific heats (C_p). (Continued)

Explosive	C_p(est.) at 20°C (293 K)[31] cal/g-°C[a]	C_p(est.) at 20°C (293 K)[31] (kJ/kg-K)[b]	C_p, experimental cal/g-°C[a]	C_p, experimental (kJ/kg-K)[b]	Ref.
LX-17-0	0.27	(1.13)	--	--	31
Minol-2	--	--	0.30 at -5°C	(1.25 at 268 K)	32
NC	-	-	0.18	(0.753)	9
(12.2% N)			0.268 at 25°C	(1.12 at 298 K)	40
(13.4% N)	--	--	0.247 at 25°C	(1.033 at 298 K)	40
(14.14% N)	--	--	0.370	(1.550)	
NG	--	--	0.356 at 35-200°C	(1.490 at 308-473 K)	1
NM[c]	--	--	$C_{sat}=104.4+(6.381\times10^{-2})t+(3.175\times10^{-4})t^2 -8.131\times10^{-7})t^3+(4.093\times10^{-9})t^4$ J/mol-°C, t in °C		41
NQ	--	--	6+0.08T at 200-460°C	--	42
	--	--	0.297 at 25°C	(1.243 at 298 K)	42
NQ[d]	--	--	$0.269+(7.0\times10^{-4})T$ at 37-167°C	--	4
NQ[e]	--	--	$0.242+(11.1\times10^{-4})T$ at 37-167°C	--	4
Octol	0.27	(1.13)	--	--	
PBX-9007	0.28	(1.17)	--	--	
PBX-9010	0.27	(1.13)	$0.247+(6.4\times10^{-4})T$ at 37-167°C	--	4
PBX-9011	0.27	(1.13)	$0.259+(6.3\times10^{-4})T$ at 37-167°C	--	4

Table 6-3. Specific heats (C_p). (Continued)

Explosive	C_p(est.) at 20°C (293 K)[31] cal/g-°C[a]	(kJ/kg-K)[b]	C_p, experimental cal/g-°C[a]	(kJ/kg-K)[b]	Ref.
PBX-9205	0.28	(1.17)			
PBX-9404	0.27	(1.13)	$0.224+(7.0\times10^{-4})T$ at 7-147°C	--	4
PBX-9407	0.27	(1.13)	$0.241+(7.7\times10^{-4})T$ at 37-167°C	--	4
PBX-9501	0.27	(1.13)	$0.238+(7.9\times10^{-4})T$ at 50-175°C	--	4
PBX-9502	--	--	$0.249+(5.9\times10^{-4})T$ at 37-177°C	--	4
Pentolite 50/50	0.26	(1.09)	--	--	
PETN	--	--	0.26 at 20°C	(1.088 at 293 K)	39
	--	--	$0.257+(5.21\times10^{-4})T$ up to 140°C		39
	--	--	$0.239+(8.0\times10^{-4})T$ at 32-127°C	--	4
Picric Acid	--	--	0.234 at 0°C	(0.979 at 273 K)	43
	--	--	0.337 at 100°C	(1.41 at 373 K)	43
	--	--	0.26	(1.09)	9
	--	--	$0.235+(7.3\times10^{-4})T$ at 37-117°C	--	4

Table 6-3. Specific heats (C_p). (Continued)

Explosive	C_p(est.) at 20°C (293 K)[31] cal/g-°C[a]	C_p(est.) at 20°C (293 K)[31] (kJ/kg-K)[b]	C_p, experimental cal/g-°C[a]	C_p, experimental (kJ/kg-K)[b]	Ref.
Polystyrene	--	--	0.283 at 0°C	(1.184 at 273 K)	12
	--	--	0.300 at 50°C	(1.255 at 323 K)	12
	--	--	0.439 at 100°C	(1.837 at 373 K)	12
RDX	--	--	0.269 at 25°C	(1.126 at 298 K)	42
	--	--	$0.236+(6.9\times10^{-4})T$	--	38
	--	--	$0.232+(7.2\times10^{-4})T$ at 37-167°C	--	35
(cryst.)	--	--	0.237 at 25°C	(0.992 at 298 K)	44
	--	--	0.0928 at -195°C	(0.388 at 78 K)	44
	--	--	8.33×10^{-3} at -258°C	(0.0349 at 15 K)	44
	--	--	7.65×10^{-4} at -266°C	(0.0032 at 7 K)	44
Sylgard 182	--	--	0.34 at 25°C	(1.423 at 298 K)	14
	--	--	--	(1.00 at 293 K)	38
TATB	--	--	$0.243+(6.3\times10^{-4})T$ at 37-137°C	--	4
	--	--	$0.215+0.0013T-(2\times10^{-6})T^2$ at 0-300°C	--	34
	--	--	$0.249+(5.9\times10^{-4})T$ at 37-177°C	--	35
	0.265	(1.109)	0.252 at 25°C	(1.054 at 298 K)	7
Tetryl	--	--	0.252 at 25°C	(1.054 at 298 K)	42
	--	--	0.225	(0.941)	9
	--	--	$0.213+(2.18\times10^{-4})T-(3.73\times10^{-7})T^2$	--	7
(liquid)	--	--	0.345 at 130-168°C	(1.443 at 403-436 K)	42

Table 6-3. Specific heats (C_p). (Continued)

Explosive	C_p(est.) at 20°C (293 K)[31]		C_p, experimental		Ref.
	cal/g-°C[a]	(kJ/kg-K)[b]	cal/g-°C[a]	(kJ/kg-K)[b]	
TNT	--	--		(1.37)	16
	--	--	$0.252+(8.44 \times 10^{-4})T$ below 80°C	--	38
	--	--	∿0.232 at RT	(∿0.97 at RT)	45
	--	--	$0.254+(7.5 \times 10^{-4})T$ below 80.5°C	--	4
	--	--	$0.329+(5.5 \times 10^{-4})T$ above 80.5°C	--	4
	--	--	0.36	(1.51)	9
Viton A	--	--	0.35	(1.464)	17
XTX-8003	0.27	(1.13)	$0.252+(8.5 \times 10^{-4})T$ at 37-127°C	--	4
XTX-8004	--	--	$0.247+(6.2 \times 10^{-4})T$ at 25-187°C	--	4

[a] Values are identical for Btu/lb-°F and cal/g-°C.
[b] Conversion factor: 1 cal/g-°C = 4.184 kJ/kg-K.
[c] C_{sat} is heat capacity at saturated liquid nitromethane under its own vapor pressure.
[d] High bulk density.
[e] Low bulk density.

6.4. THERMAL STABILITY

Thermal changes in materials can be measured in several ways, qualitatively and quantitatively. For HEs, v generally use differential thermal analysis (DTA), thermogravimetric .alysis (TGA), and tests (pyrolysis, CRT, or vacuum stability) that measure the amount of gas evolved when the HE is heated for a stated period of time at an elevated temperature. Heating rates are generally 10°C/min. Critical temperatures (T_c) are also given, although they are dependent on the initial sample temperature, experimental configuration, heat input, pressure, and other variables.

6.4.1. Differential thermal analysis (DTA)

In the usual DTA analysis, identical containers are set up (one containing the sample and the other containing a standard reference substance) in identical thermal geometries with temperature sensors arranged to give both the temperature of each container and the difference in temperatures between containers. The data are displayed as DTA thermograms; the temperature difference is plotted against the temperature of the sample. The standard reference material chosen is one whose thermal behavior does not change rapidly. Such a plot is nearly a straight line if the sample also has no rapidly changing thermal behavior (or if it is very similar to the standard material). Excursions above and below a background line result from endo- or exothermic (heat-absorbing or heat-releasing) changes. The DTA analyses permit interpretation for phase changes, decomposition and kinetic information, melting points, and thermal stability (Fig. 6-6). Sample sizes are less than 40 mg.[46,47]

6.4.2. Pyrolysis

The sample is placed in a pyrolysis chamber that is then flushed with helium. When the air has been swept out, the temperature of the chamber is raised at a constant rate. Gas evolution is measured as a function of temperature by a bridge formed by two thermal conductivity cells. Data are included in Fig. 6-6; the right-hand ordinate shows the thermal conductivity response in millivolts (mV).[48] Sample sizes are about 10 mg.

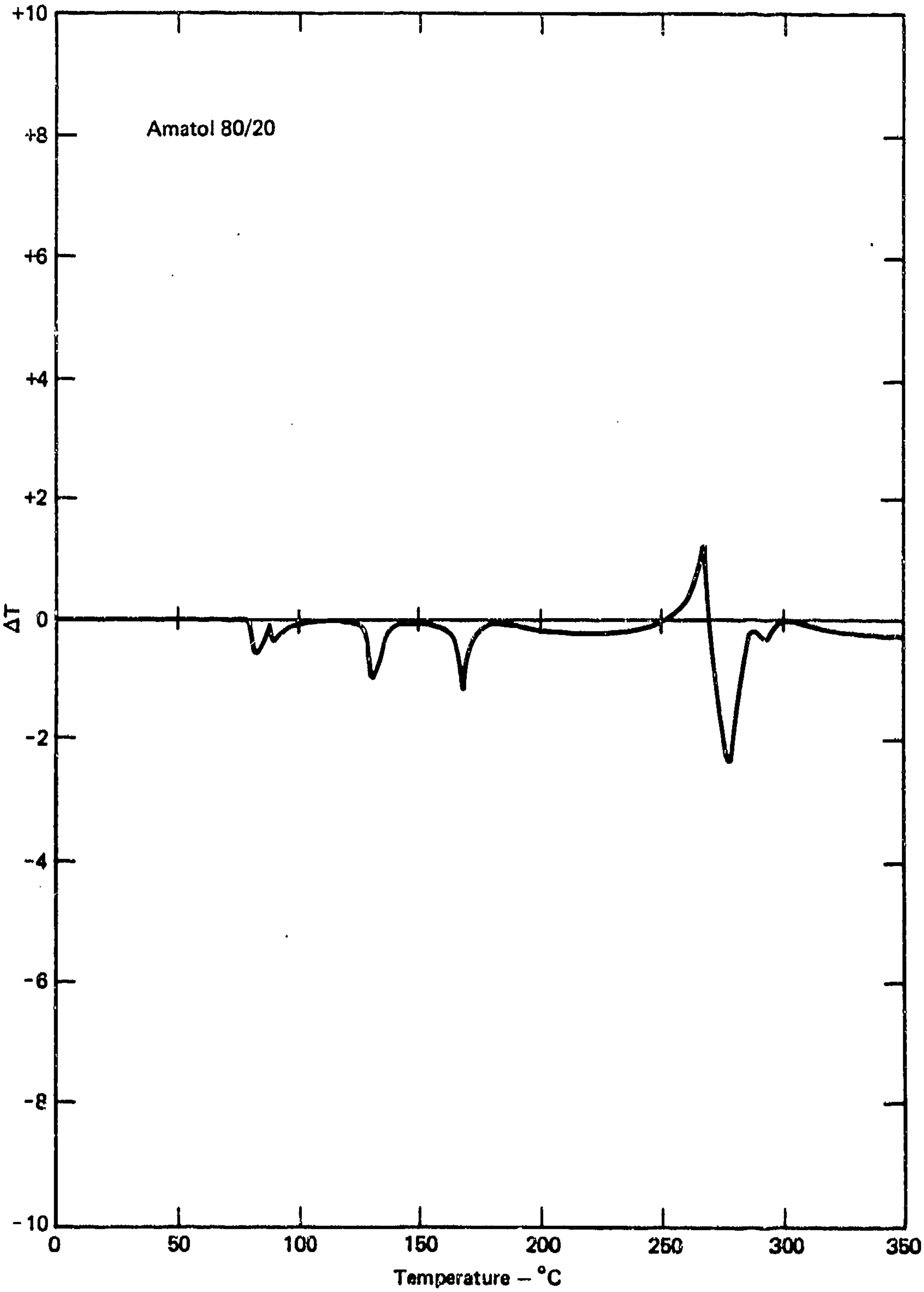


Fig. 6-6a. DTA curve of Amatol 80/20.[46]

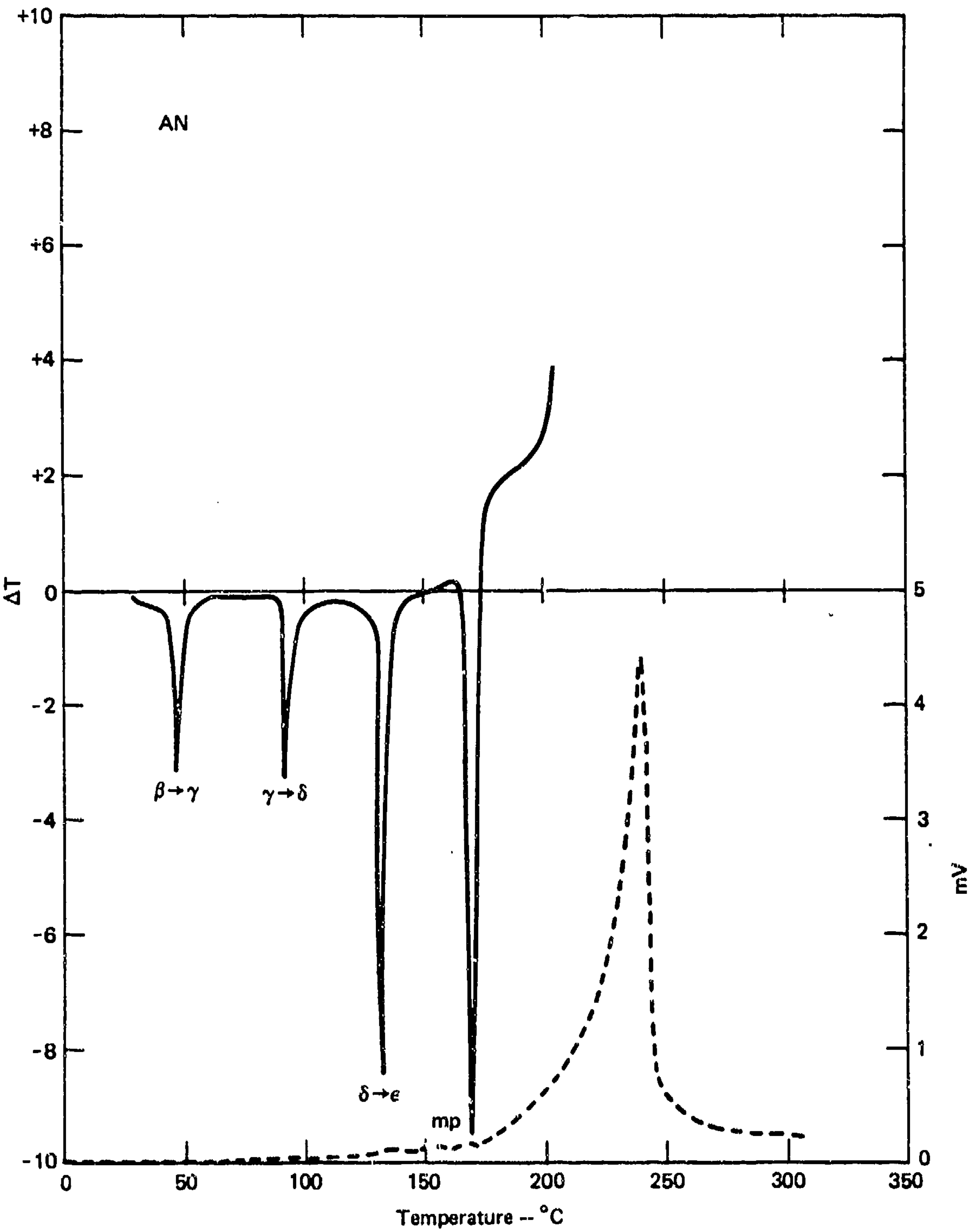


Fig. 6-6b. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for ammonium nitrate.[47]

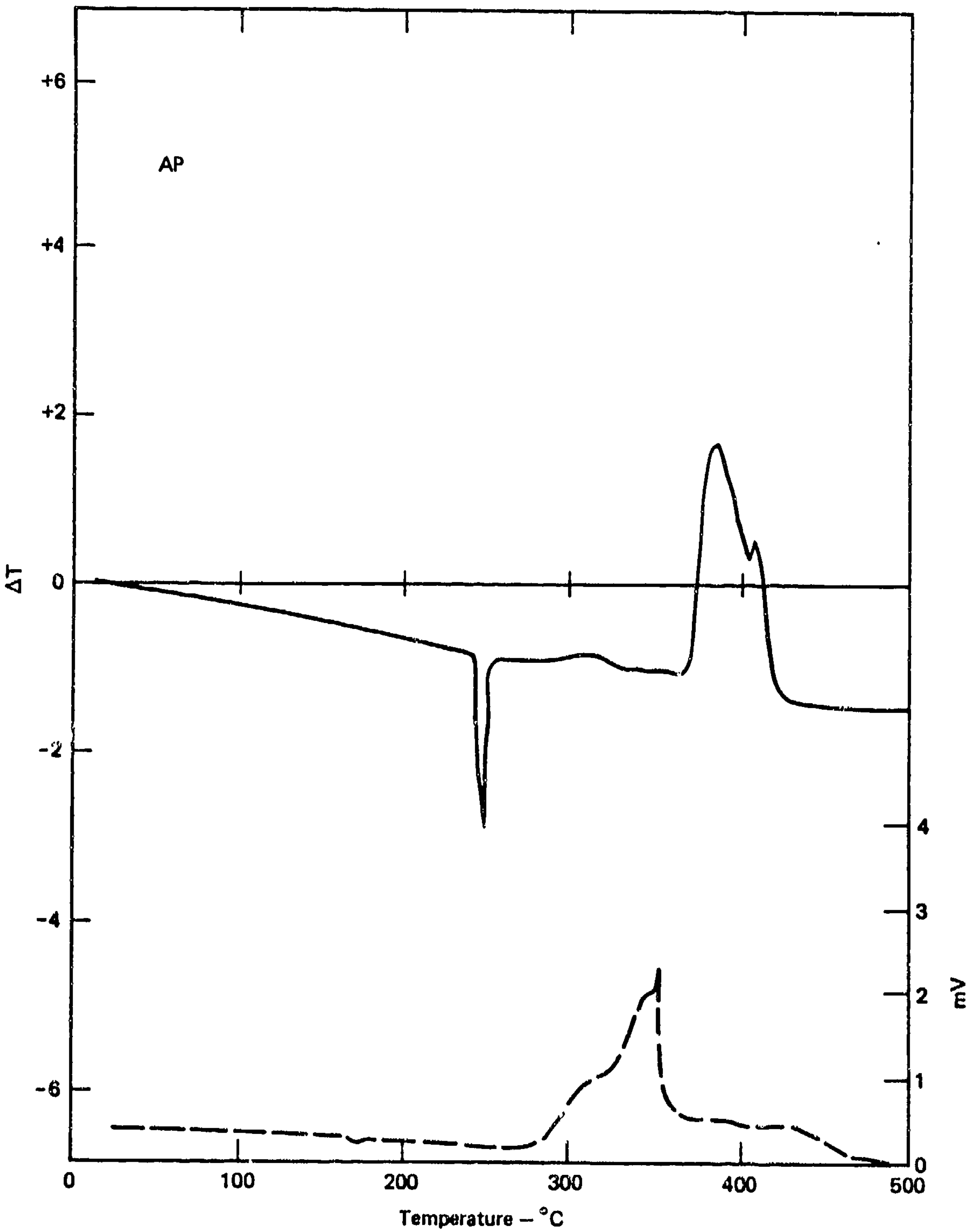


Fig. 6-6c. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for ammonium perchlorate.[47]

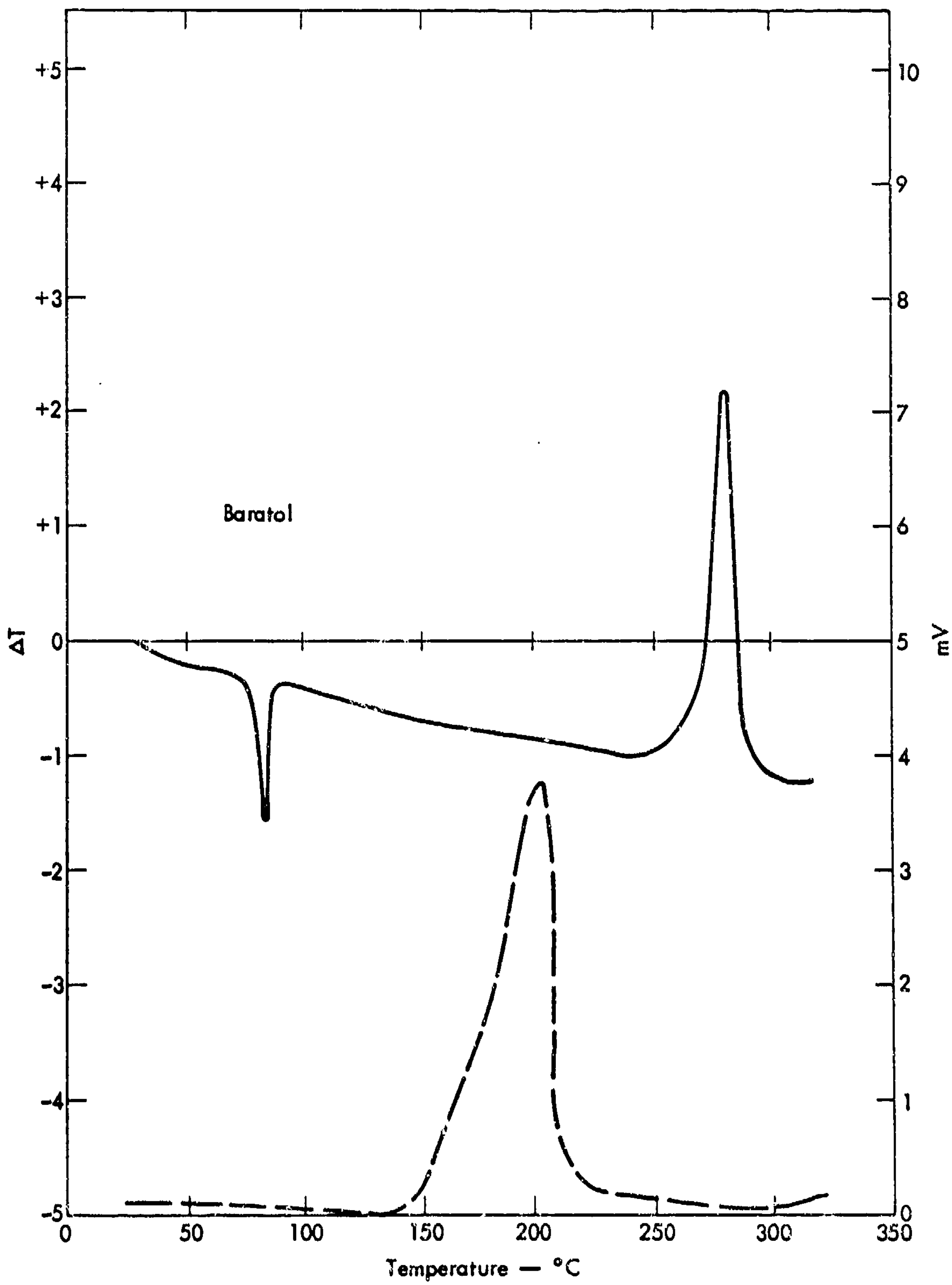


Fig. 6-6d. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Baratol.[47]

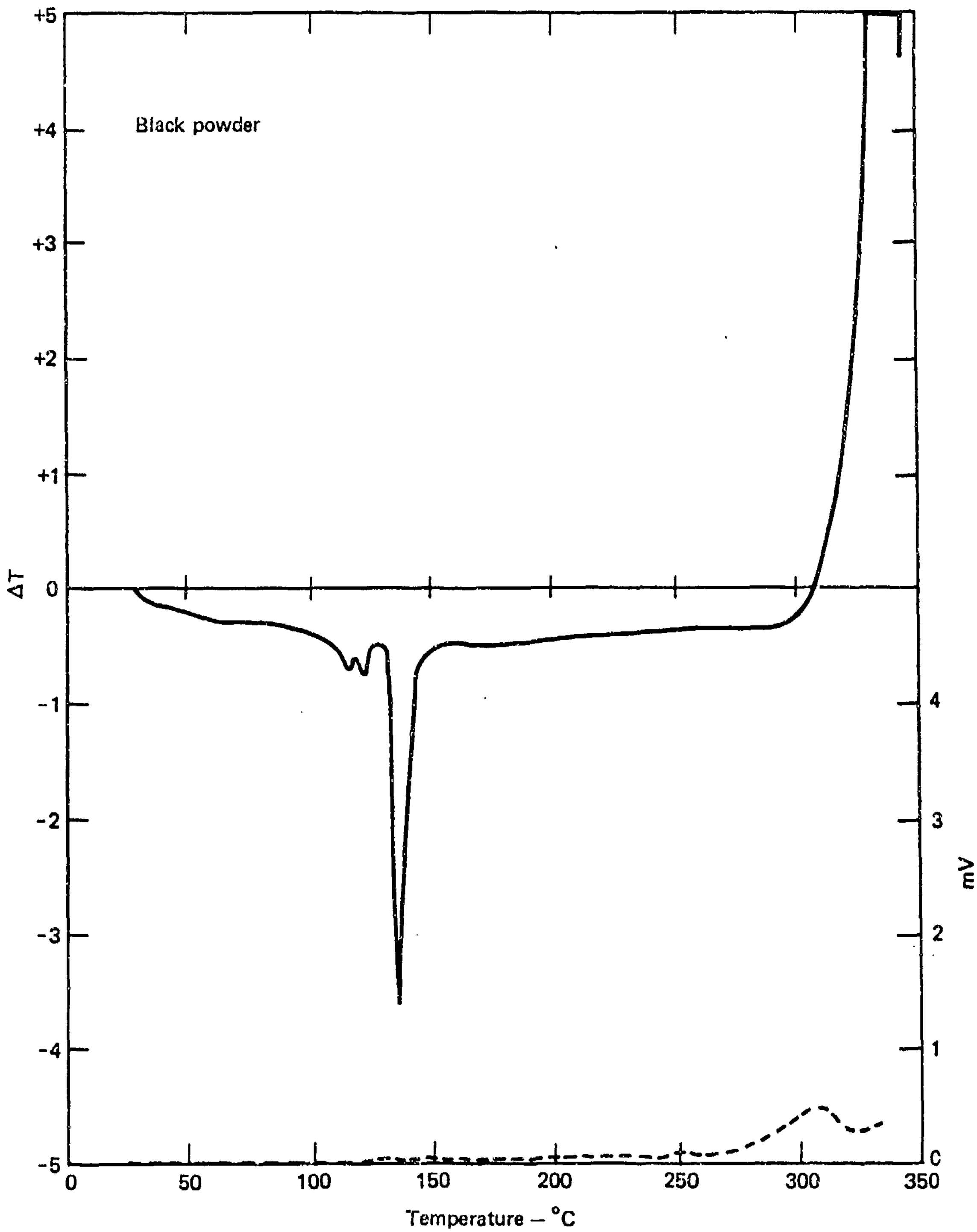


Fig. 6-6e. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for black powder.[47]

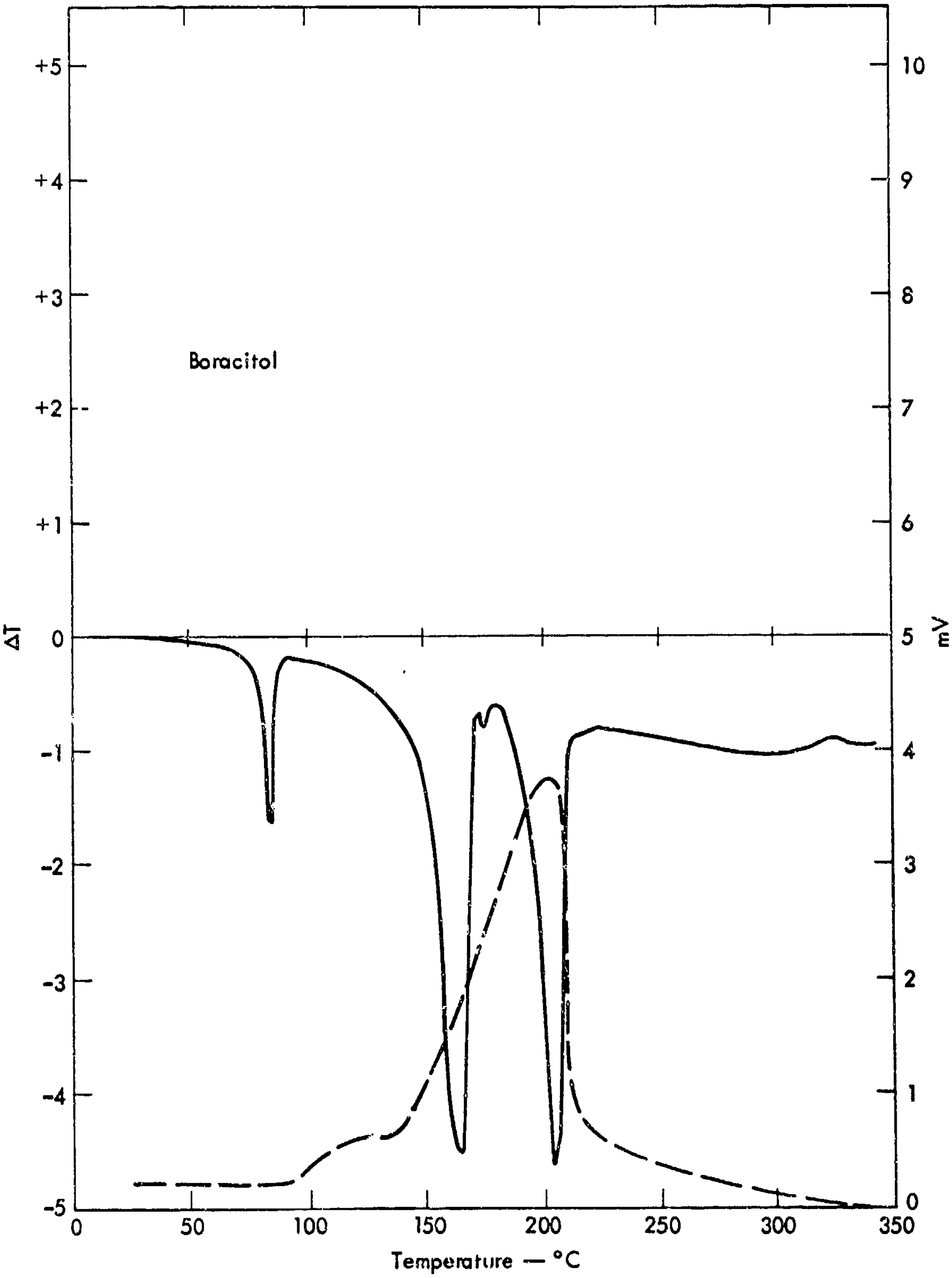


Fig. 6-6f. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Boracitol.[47]

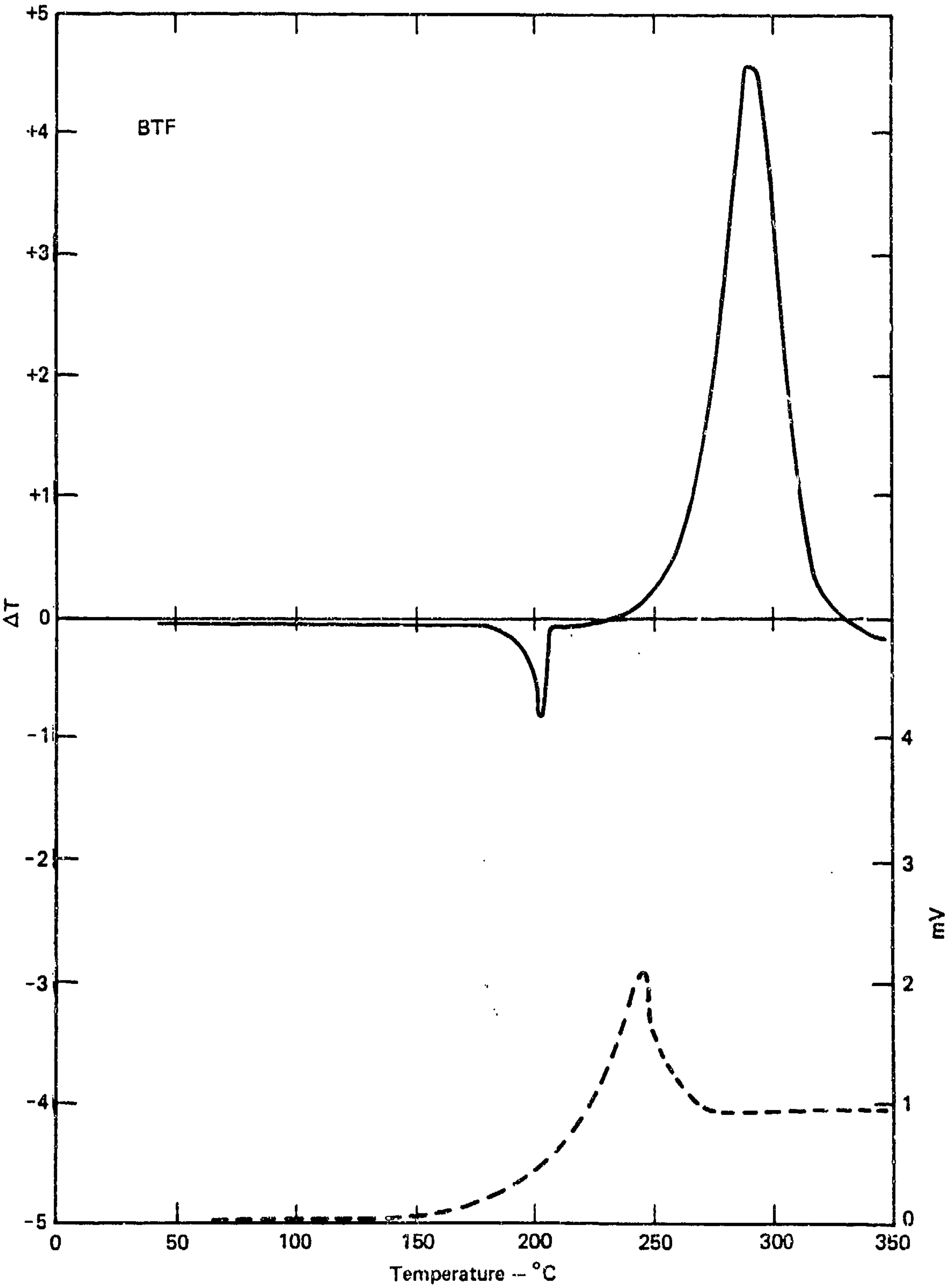


Fig. 6-6g. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for BTF.[47]

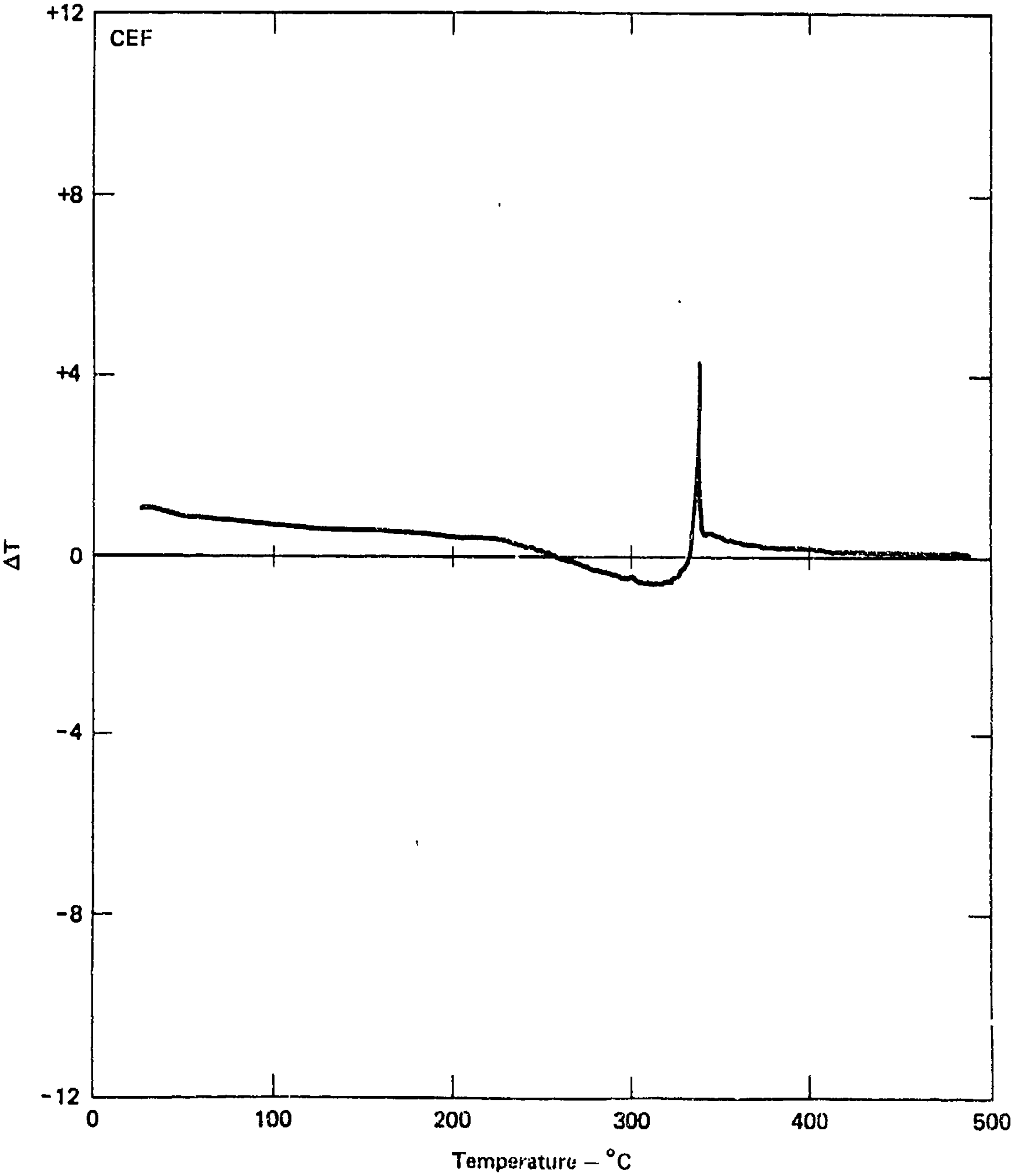


Fig. 6-6h. DTA curve for CEF.[46]

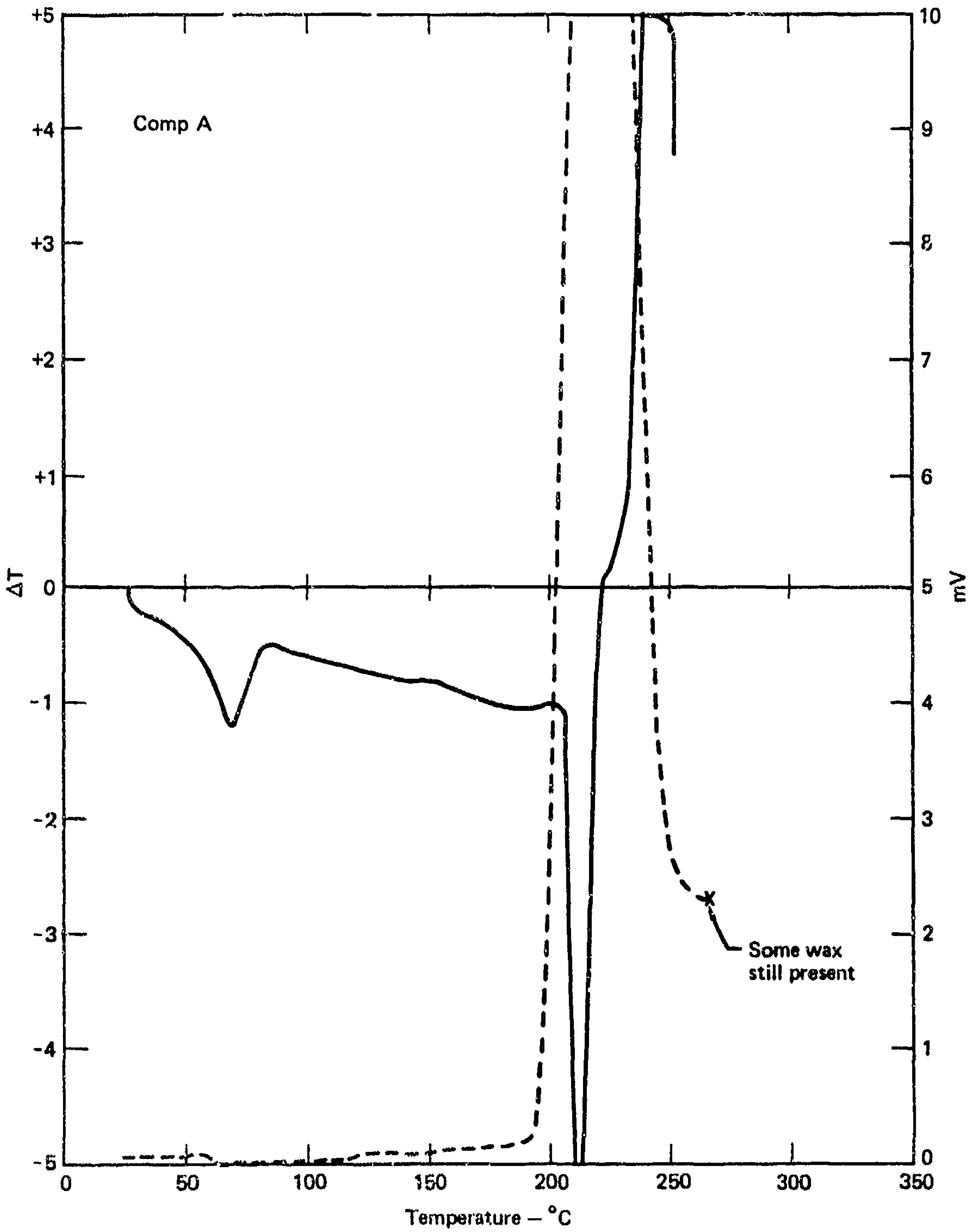


Fig. 6-6i. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Comp A.[47]

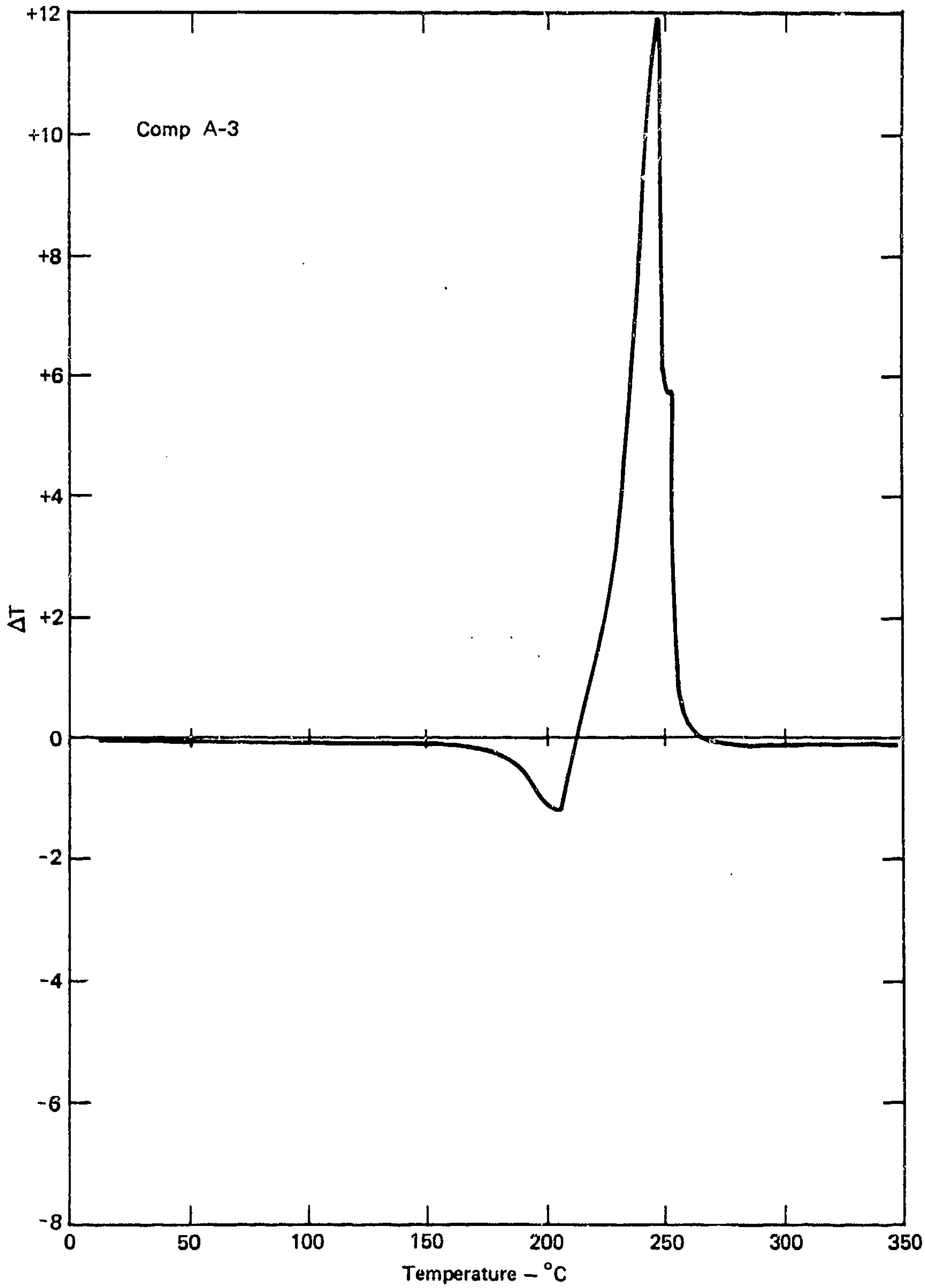


Fig. 6-6j. DTA curve for Comp A-3.[46]

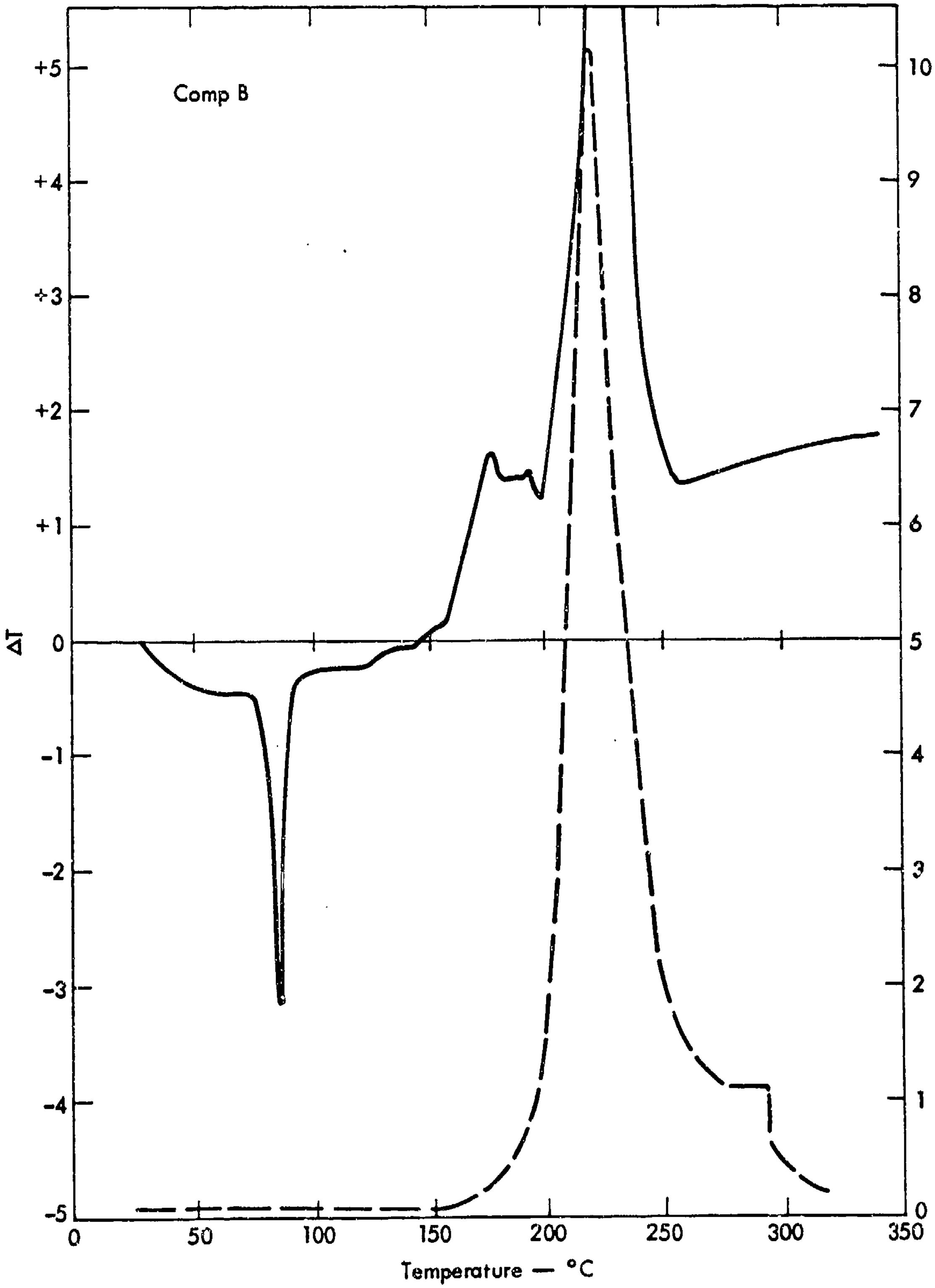


Fig. 6-6k. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Comp B.[47]

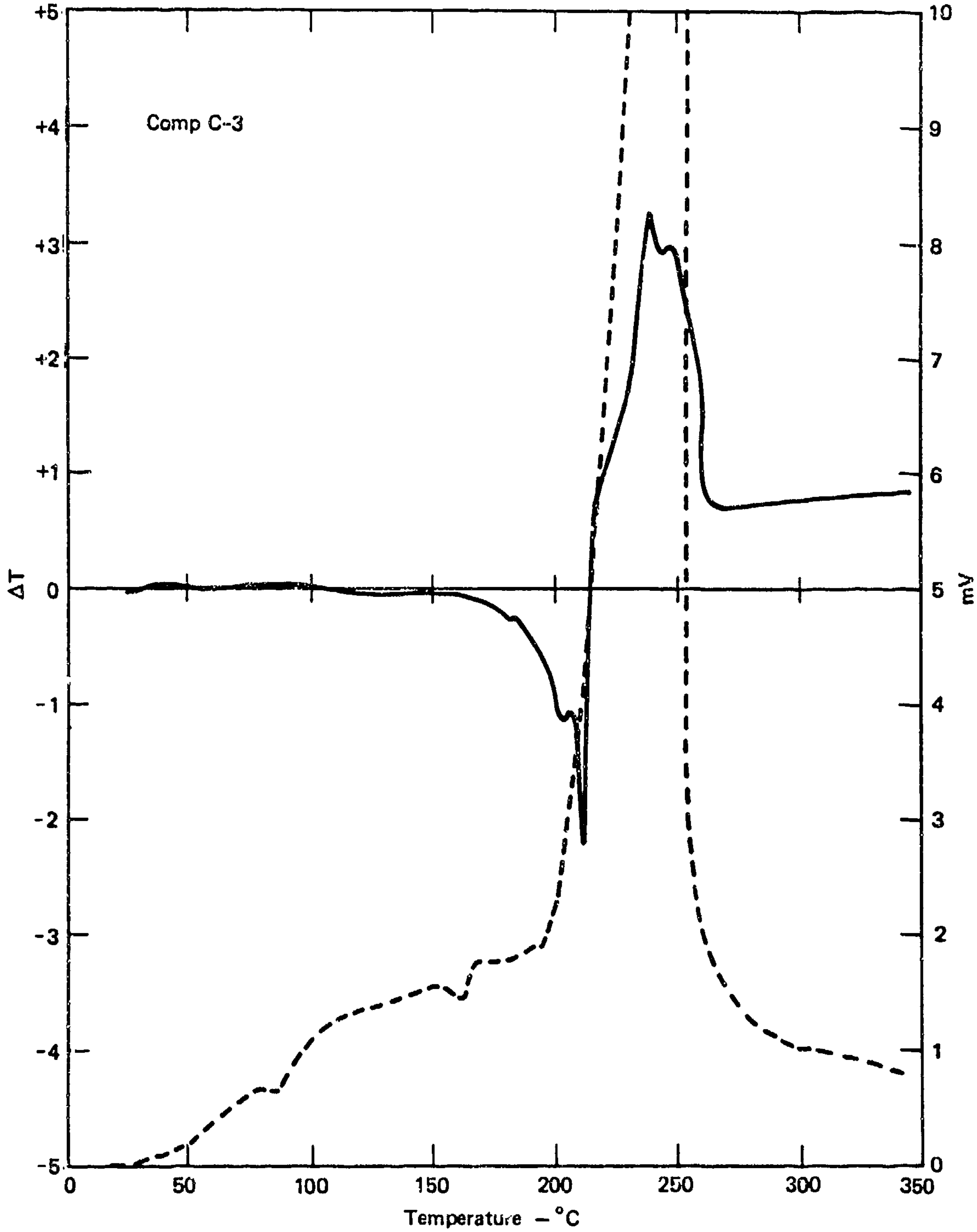


Fig. 6-61. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Comp C-3.[47]

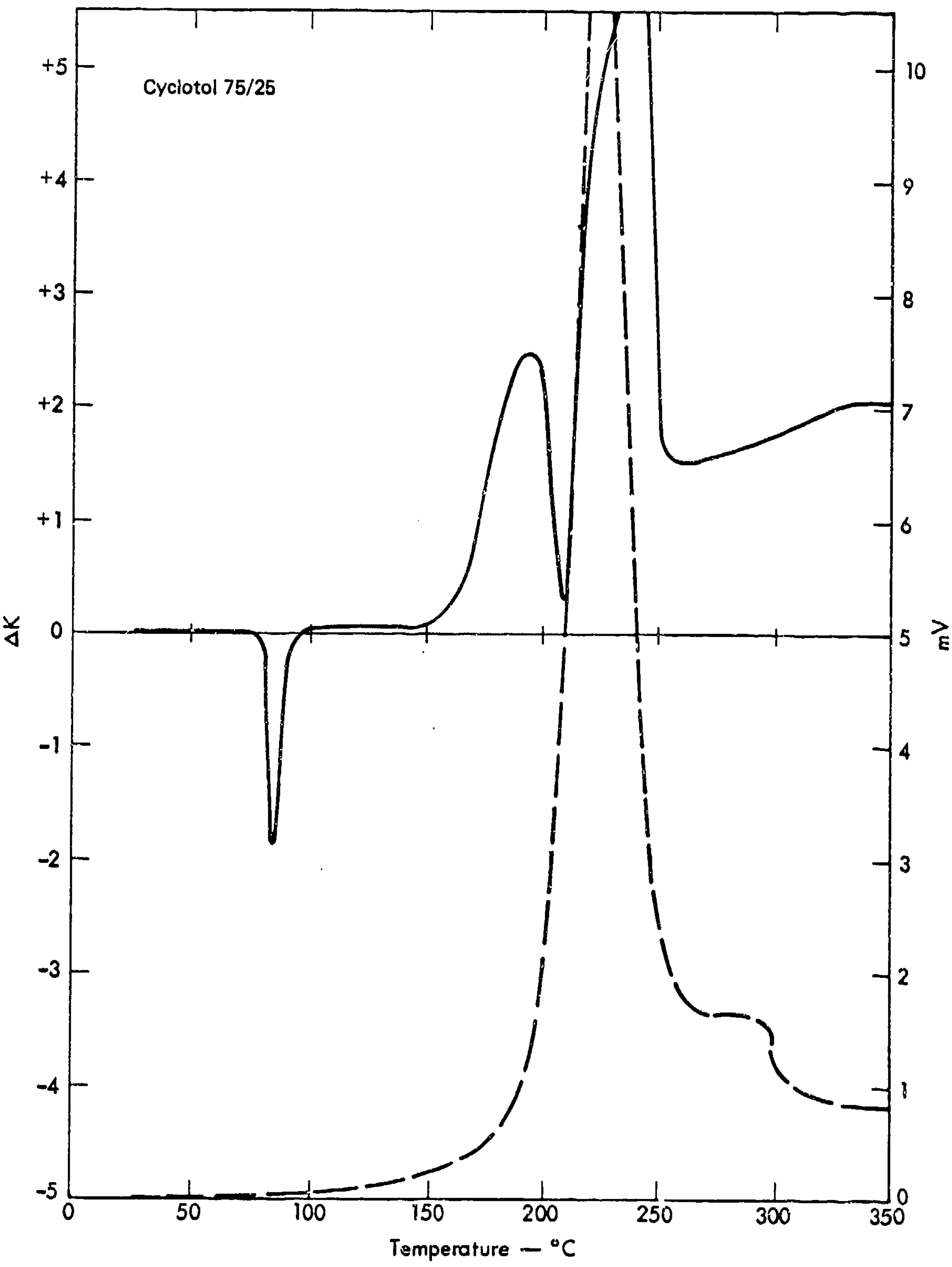


Fig. 6-6m. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Cyclotol 75/25.[47]

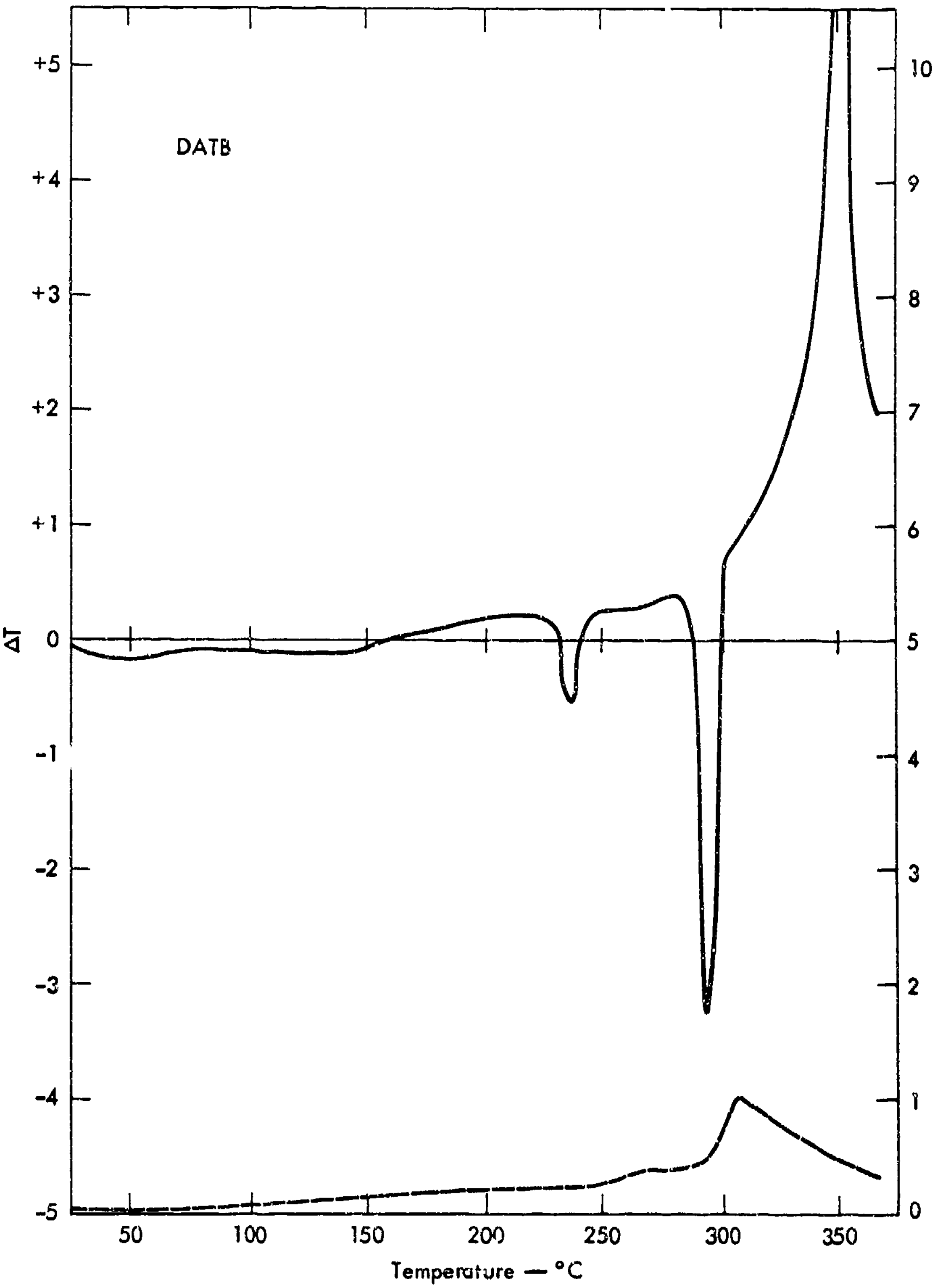


Fig. 6-6n. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for DATB.[47]

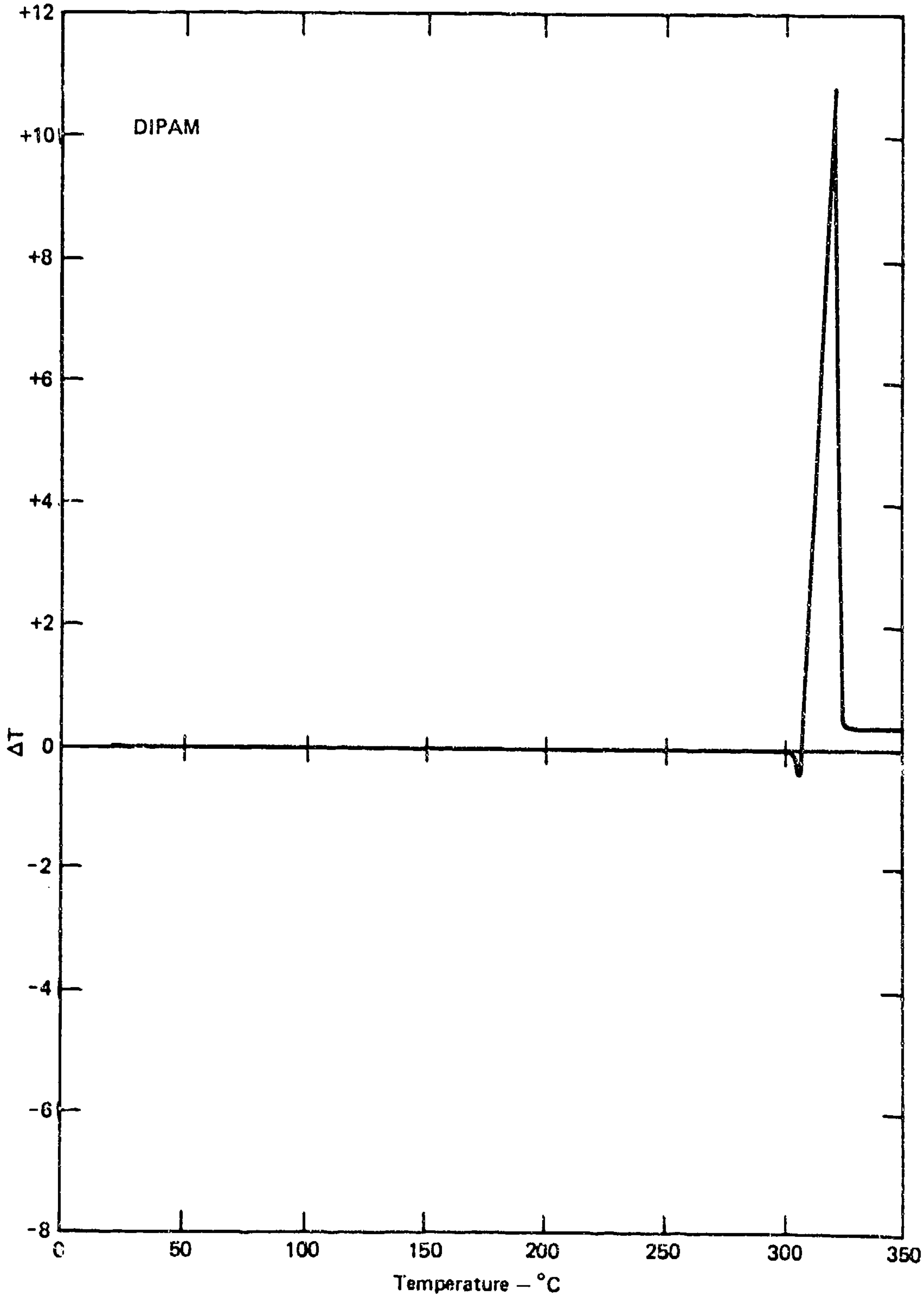


Fig. 6-6o. DTA curve for DIPAM.[46]

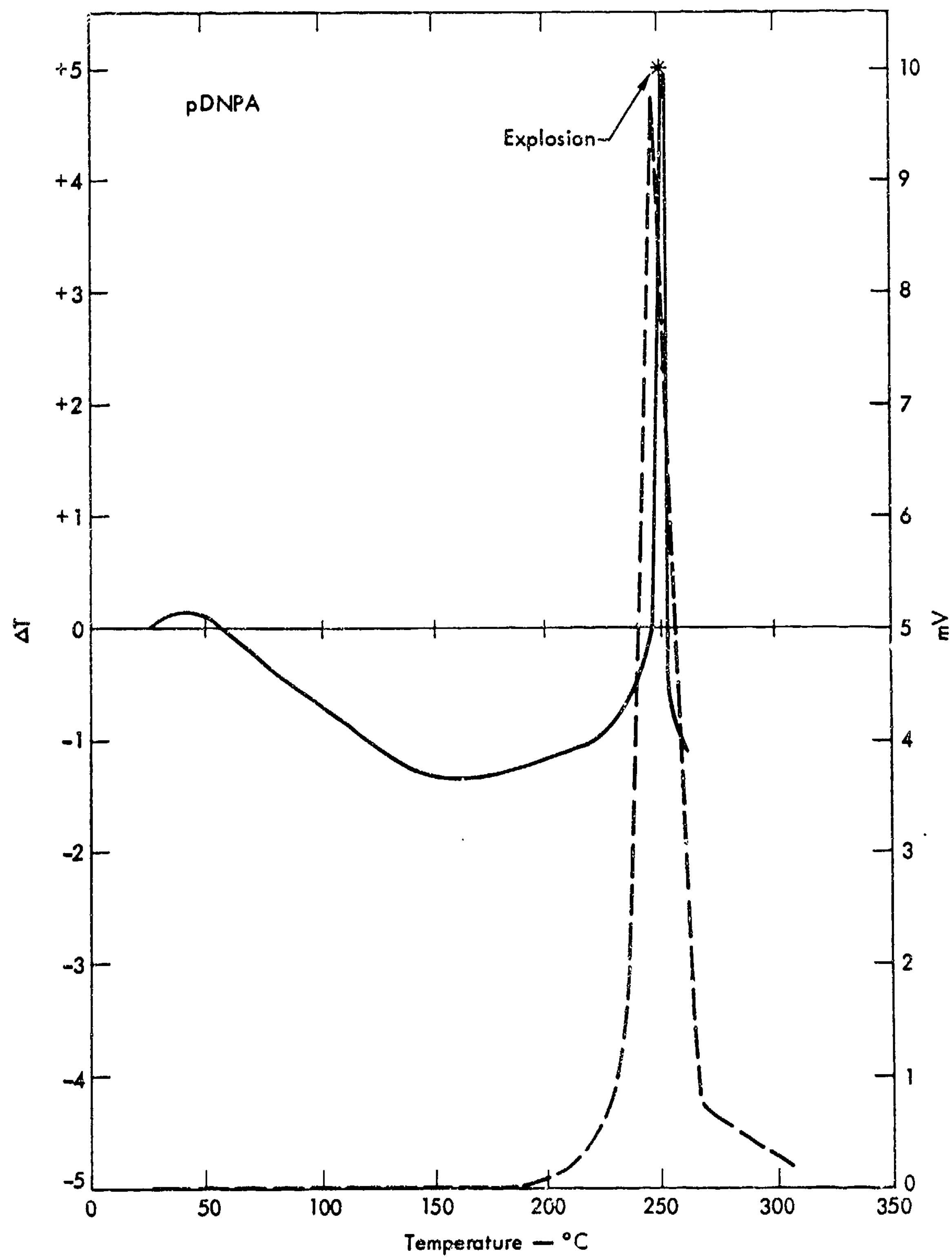


Fig. 6-6p. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for pDNPA.[47]

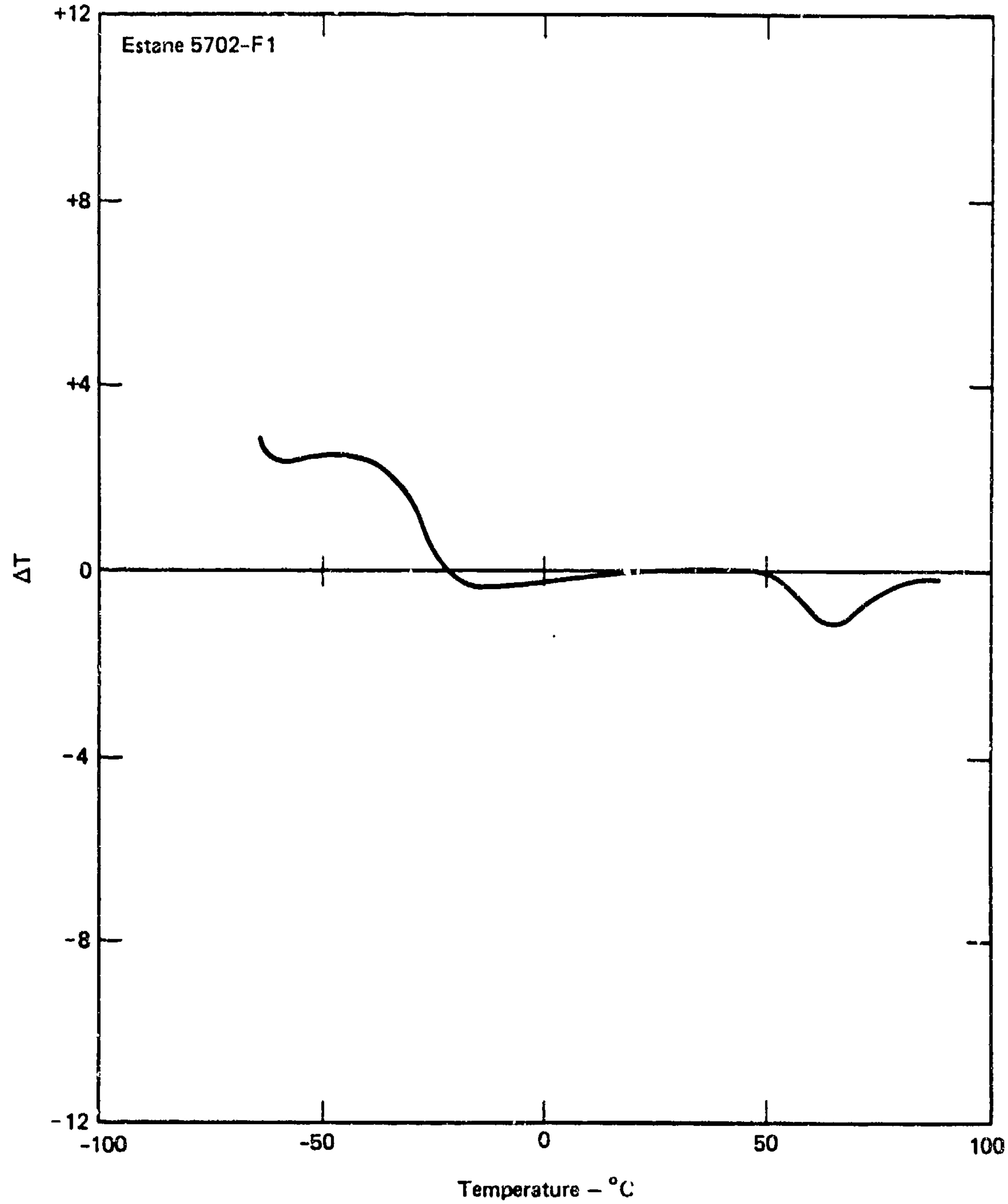


Fig. 6-6q. DTA curve for Estane 5702-F1.[46]

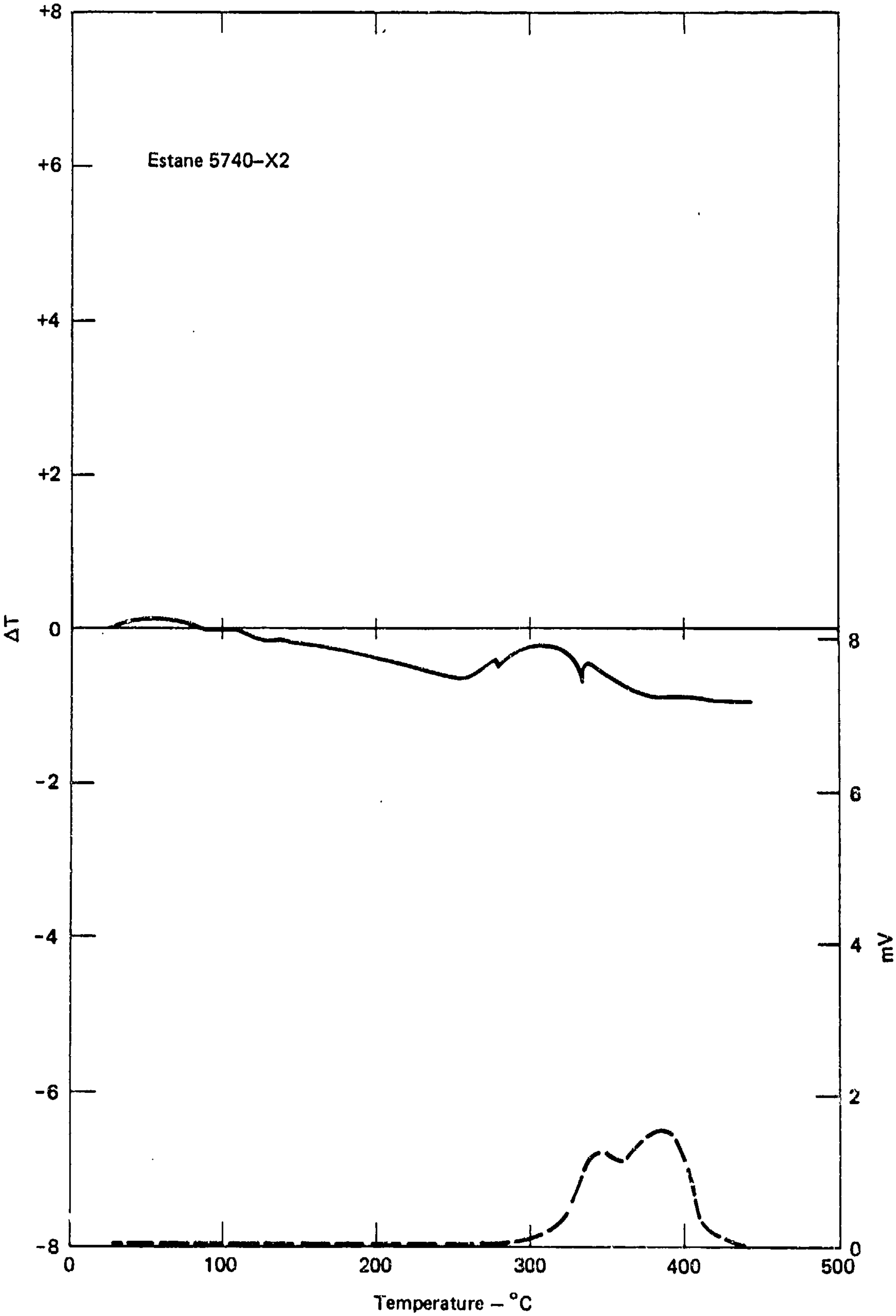


Fig. 6-6r. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Estane 5740-X2.[47]

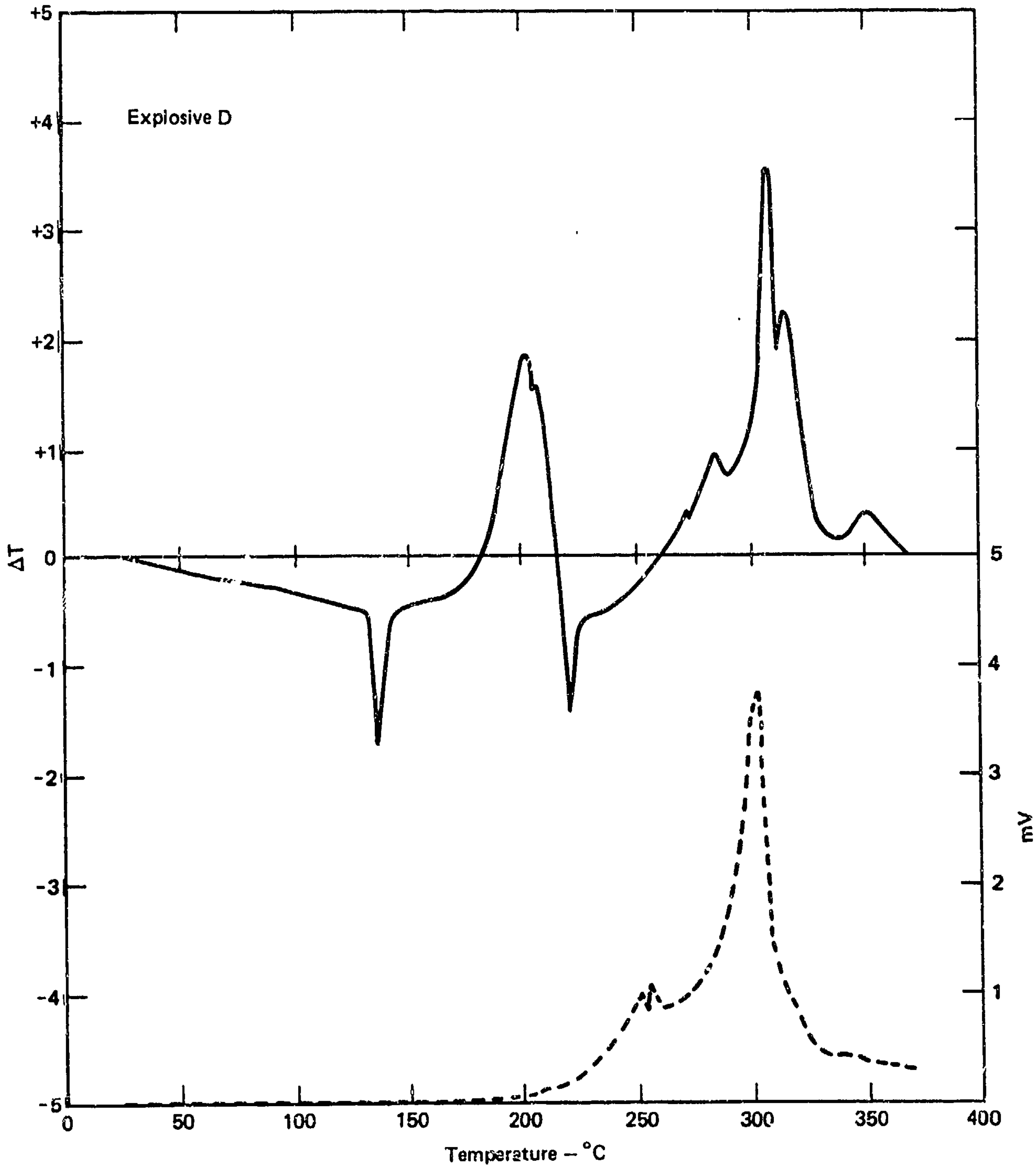


Fig. 6-6s. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Explosive D.[47]

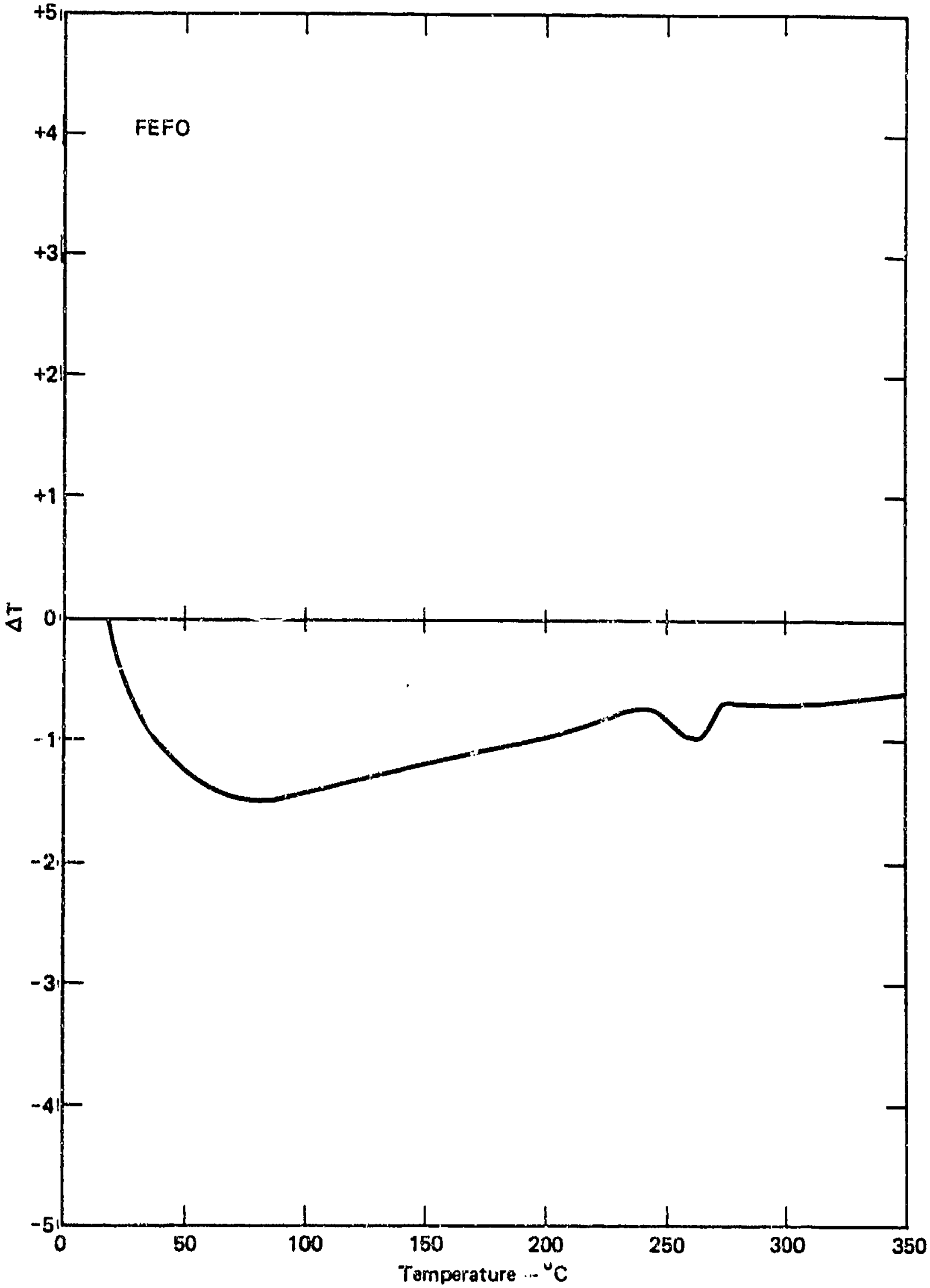


Fig. 6-6t. DTA curve for FEFO.[46]

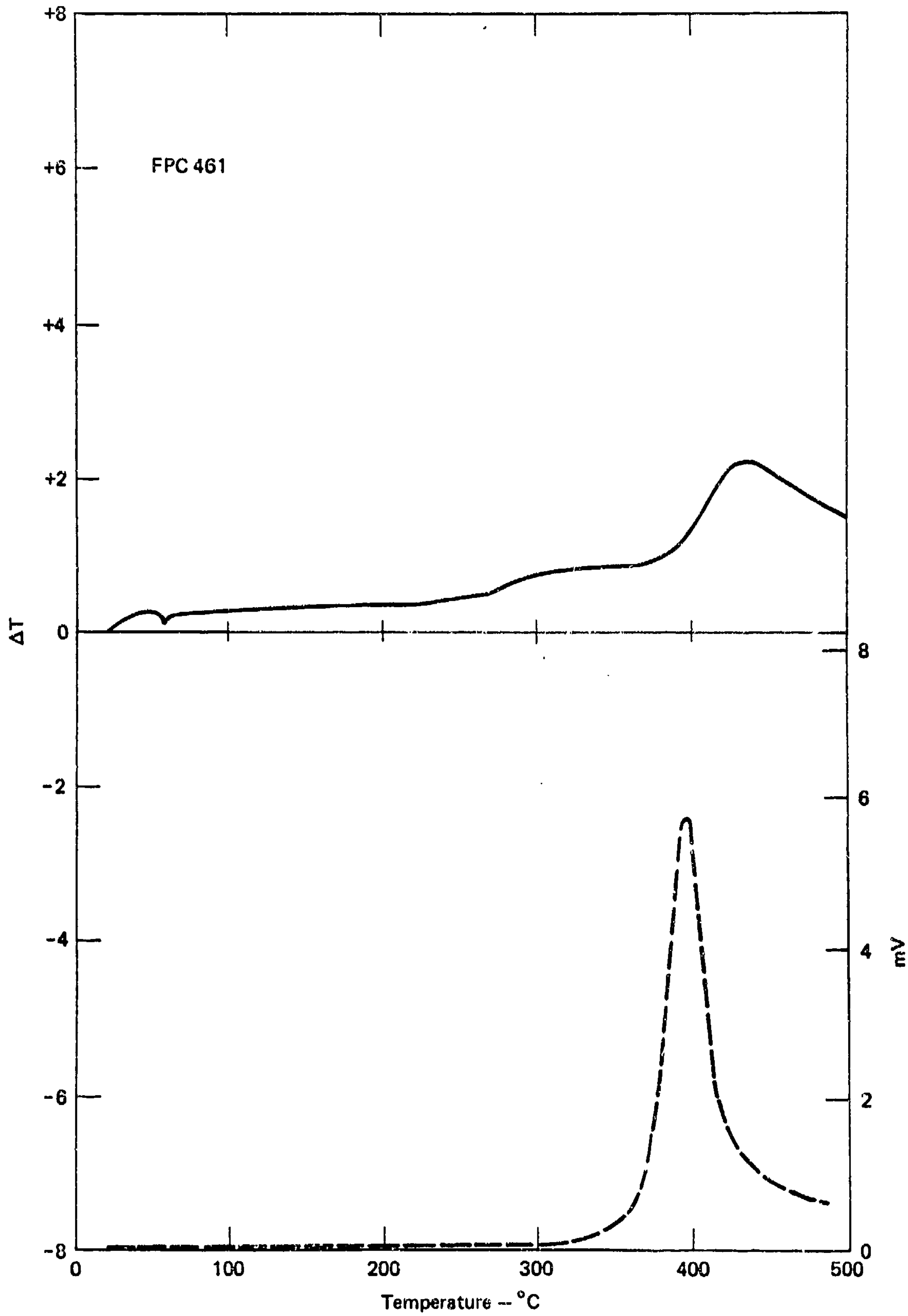


Fig. 6-6u. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for FPC 461.[47]

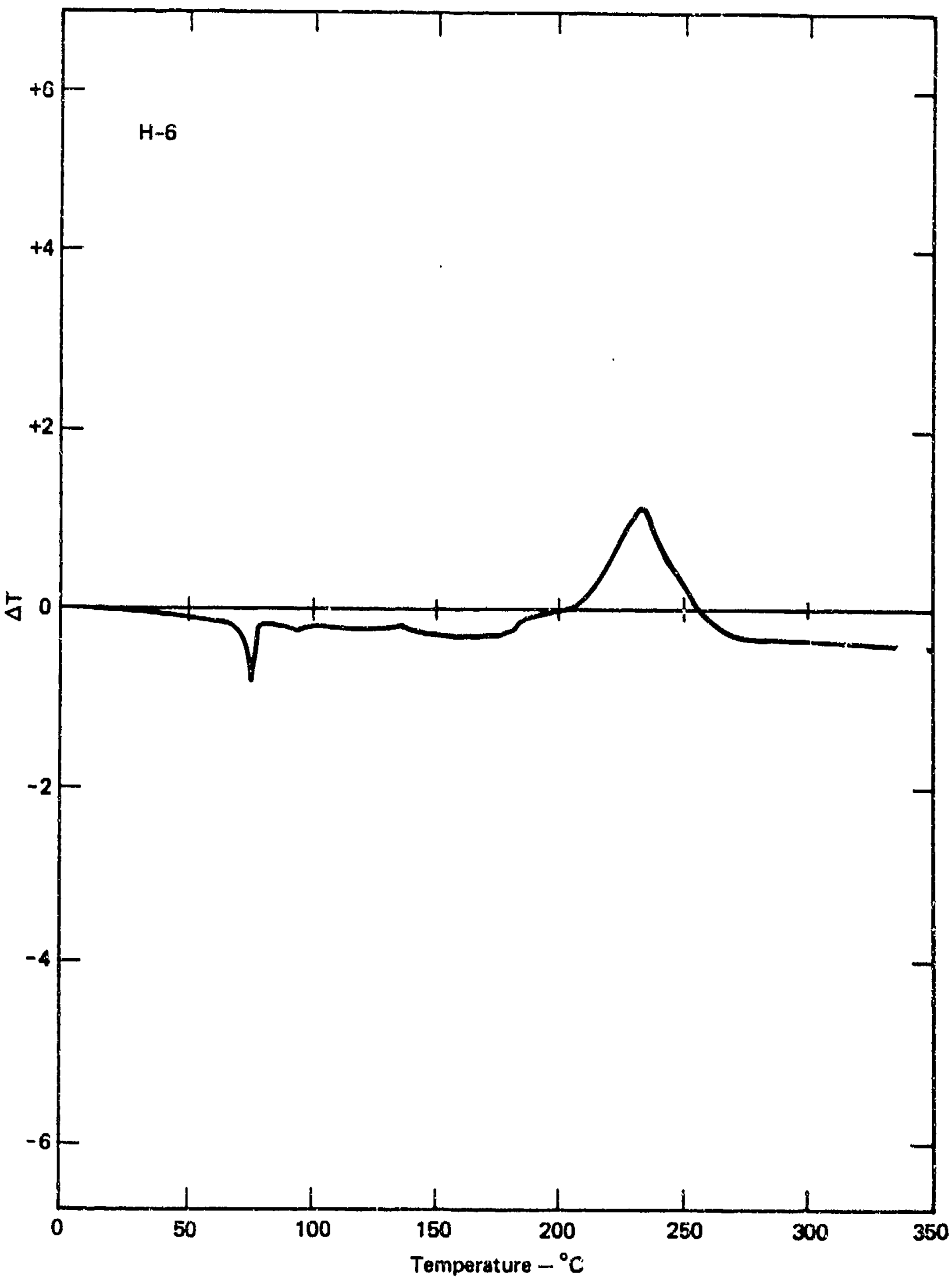


Fig. 6-6v. DTA curve for H-6.[55]

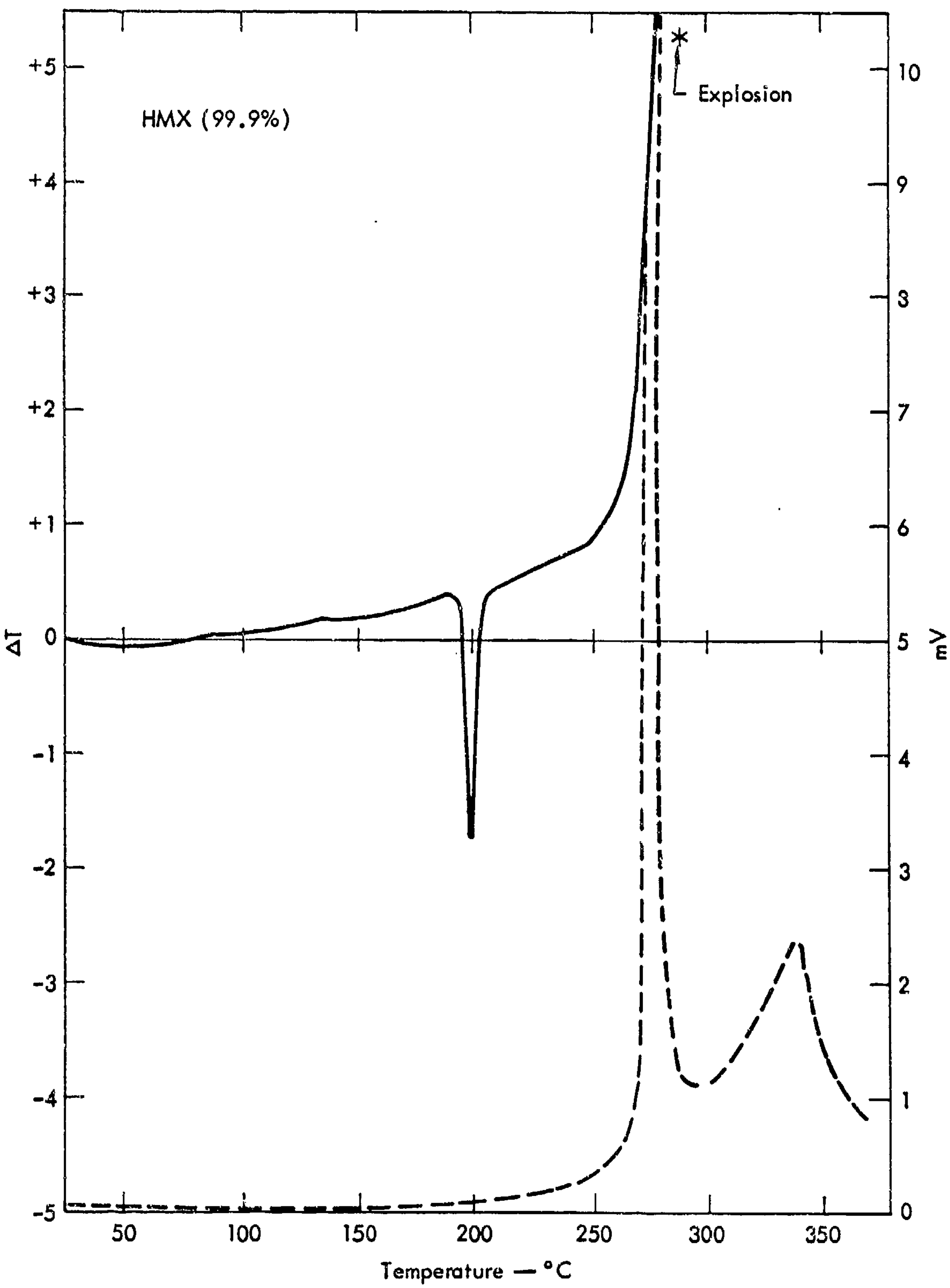


Fig. 6-6w. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for HMX (99.9% pure).[47]

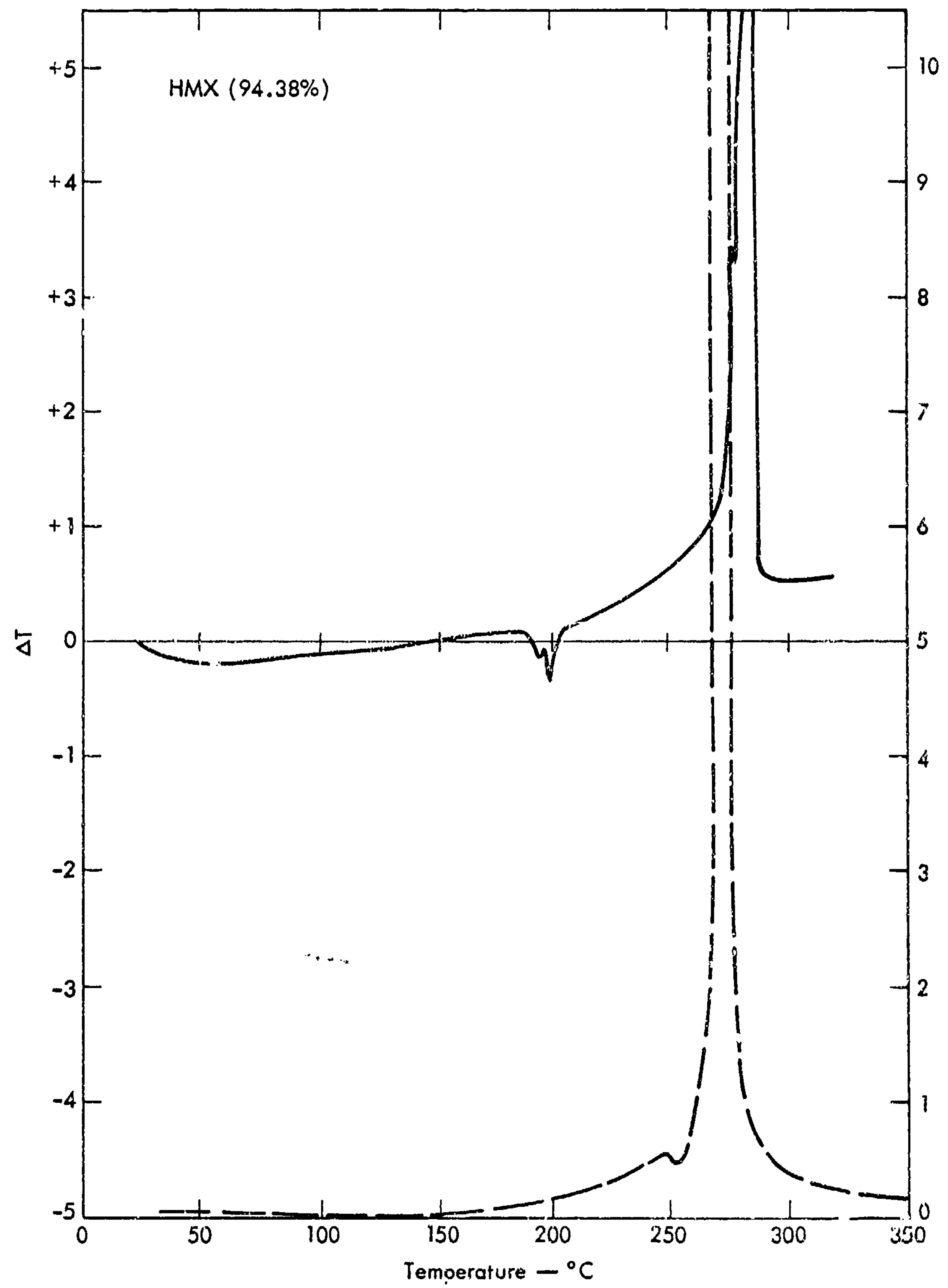


Fig. 6-6x. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for HMX (Holston production grade).[47]

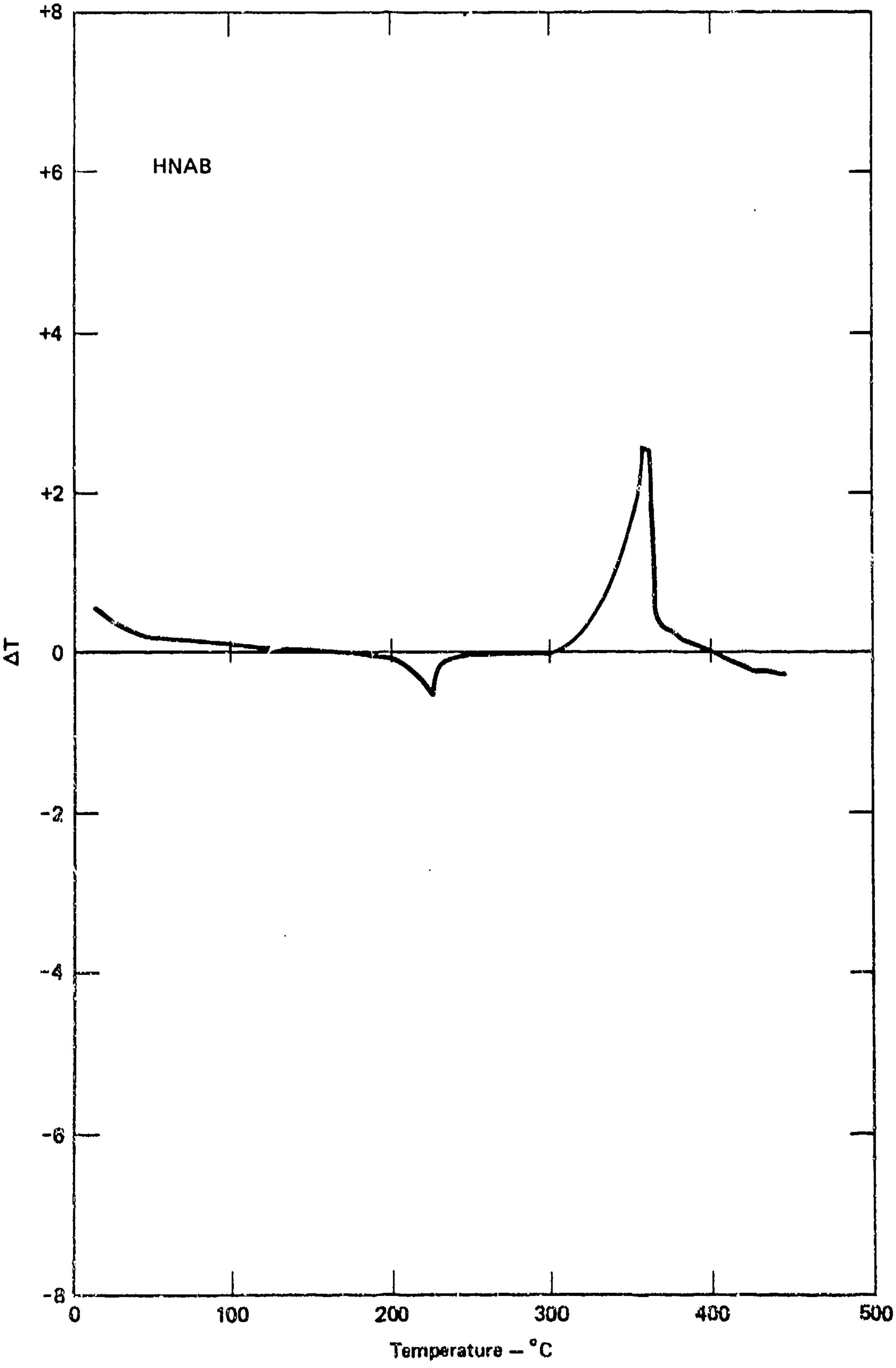


Fig. 6-6v. DTA curve for HNAB.[47]

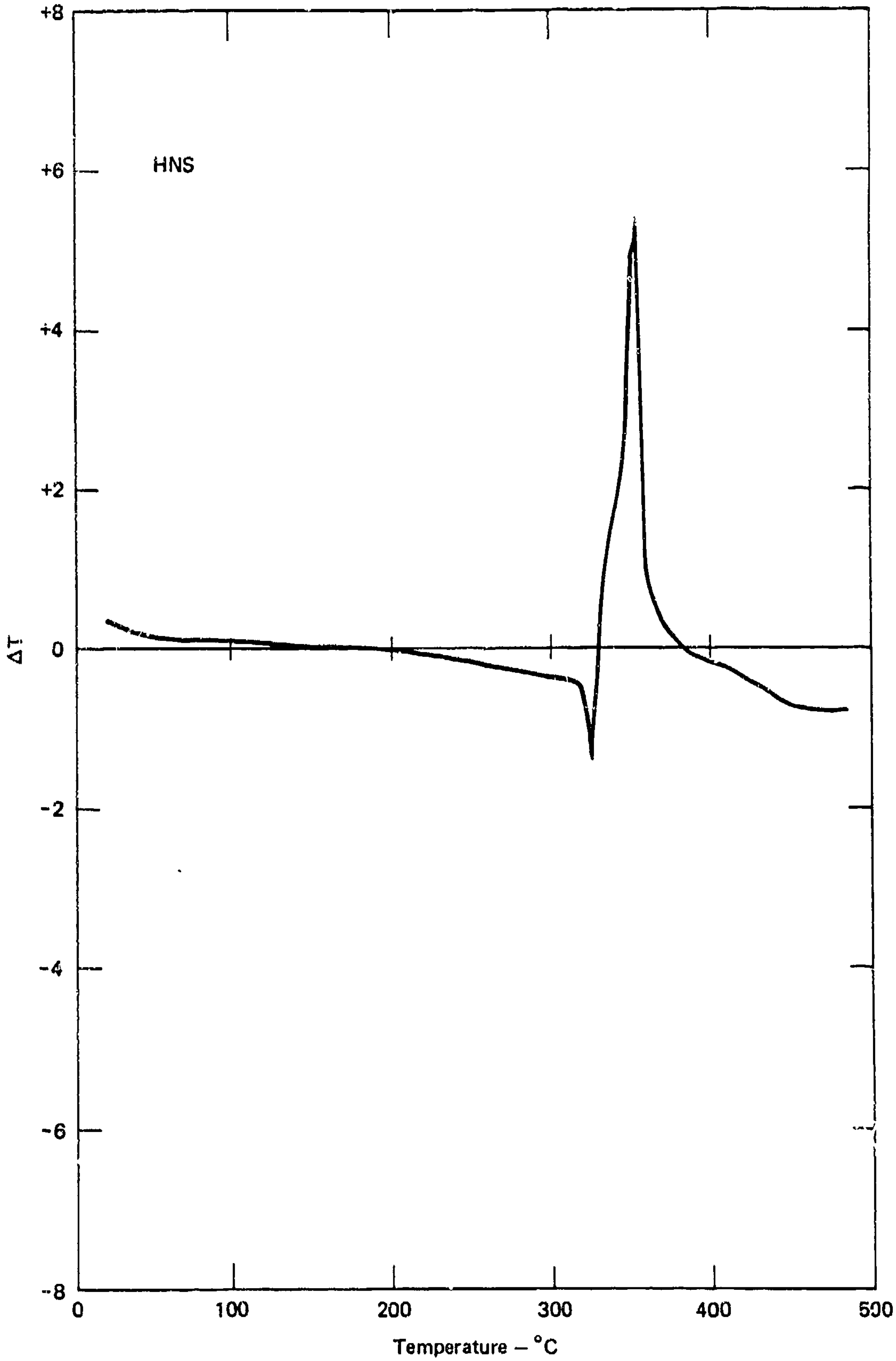


Fig. 6-6z. DTA curve for HNS.[24]

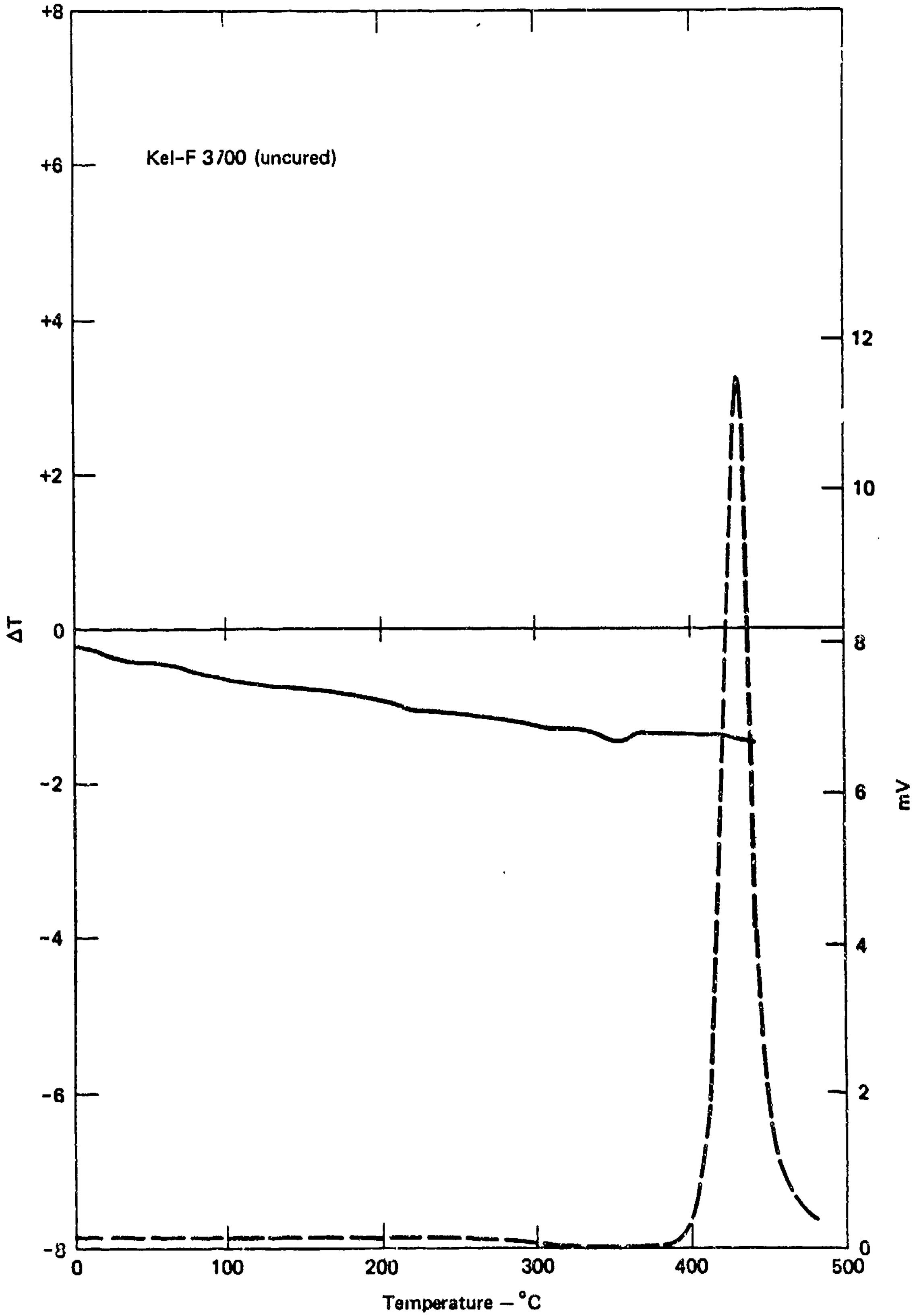


Fig. 6-6aa. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Kel-F 3700 (uncured).[47]

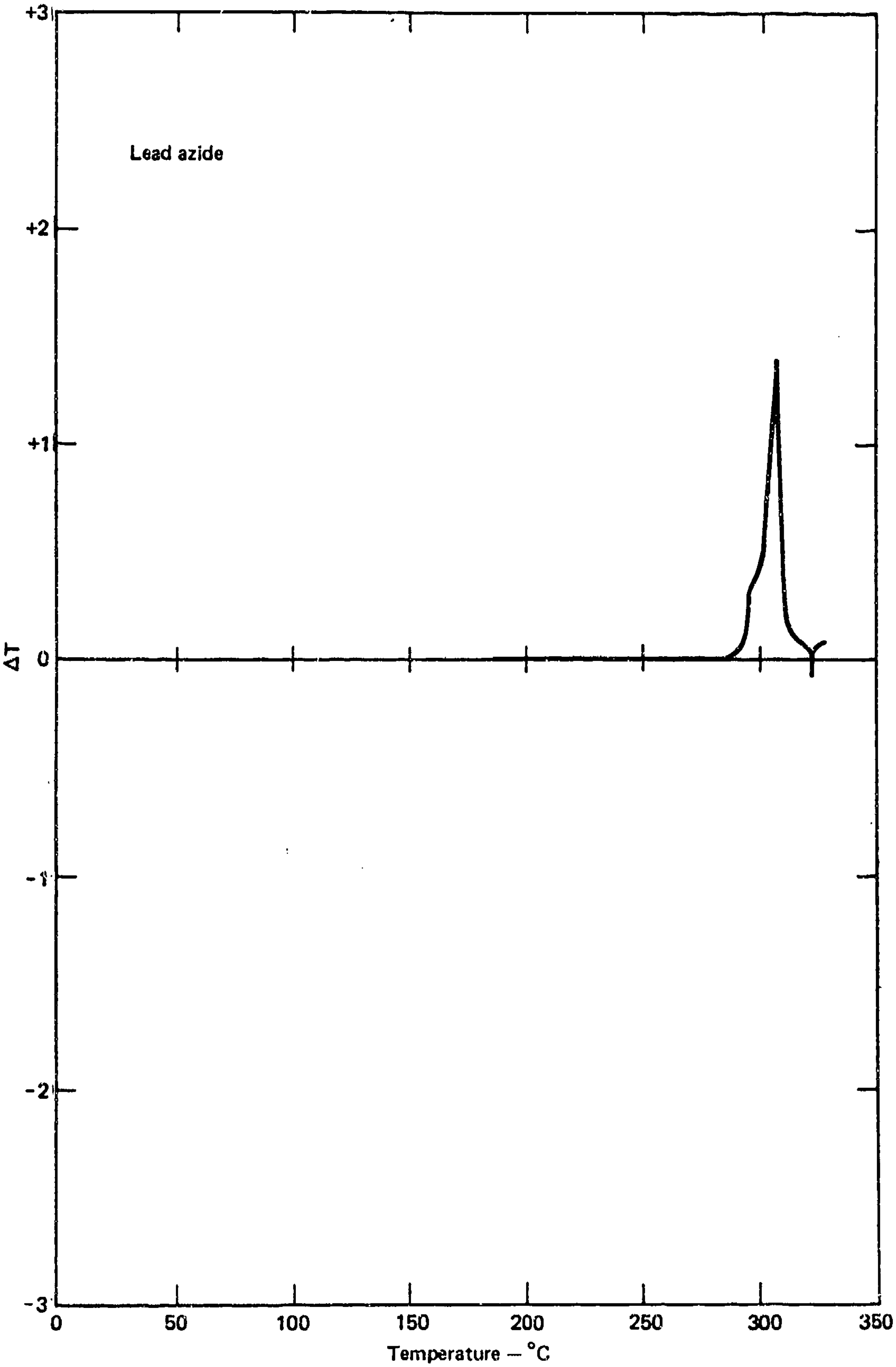


Fig. 6-6bb. DTA curve for lead azide.[56]

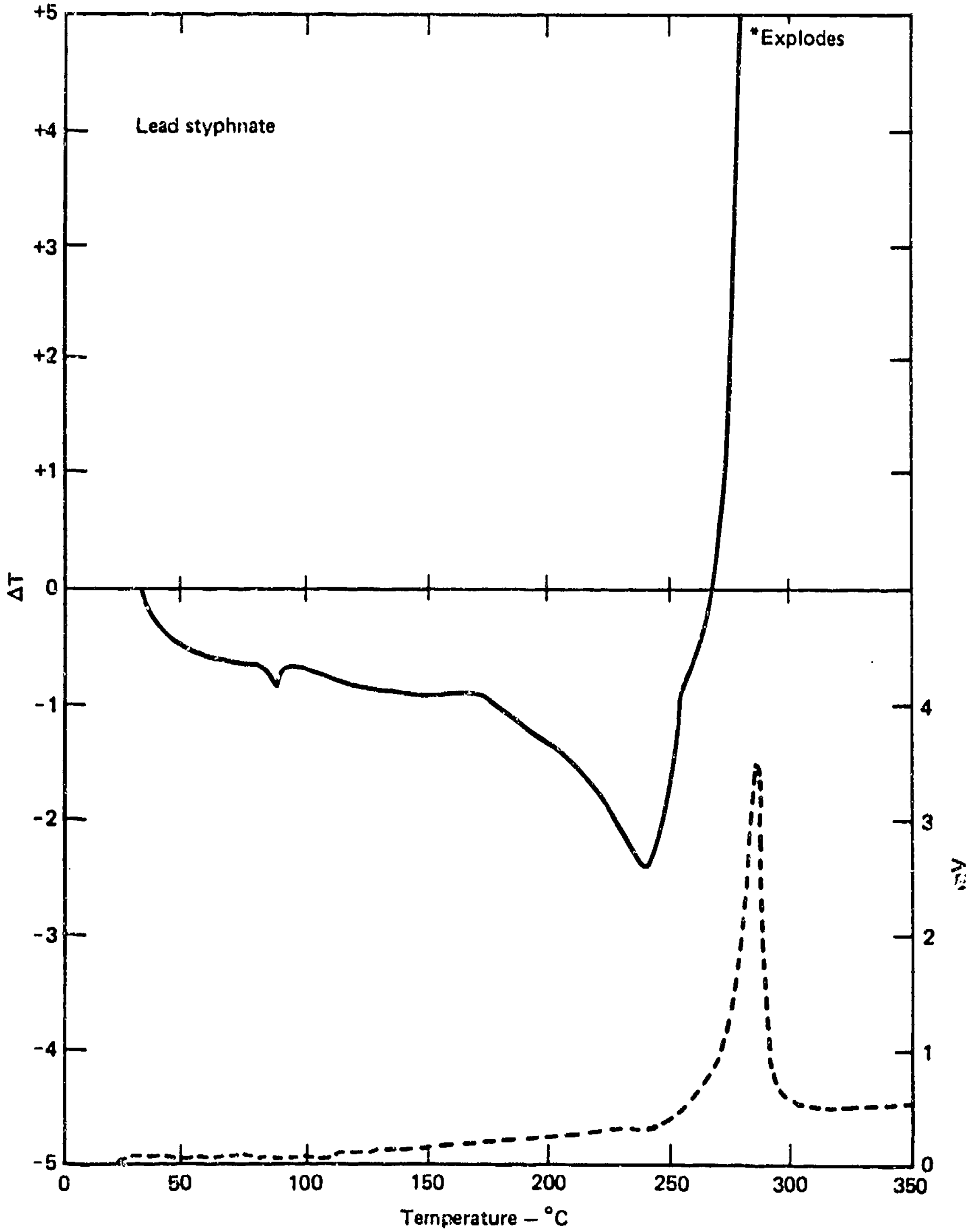


Fig. 6-6cc. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for lead styphnate.[47]

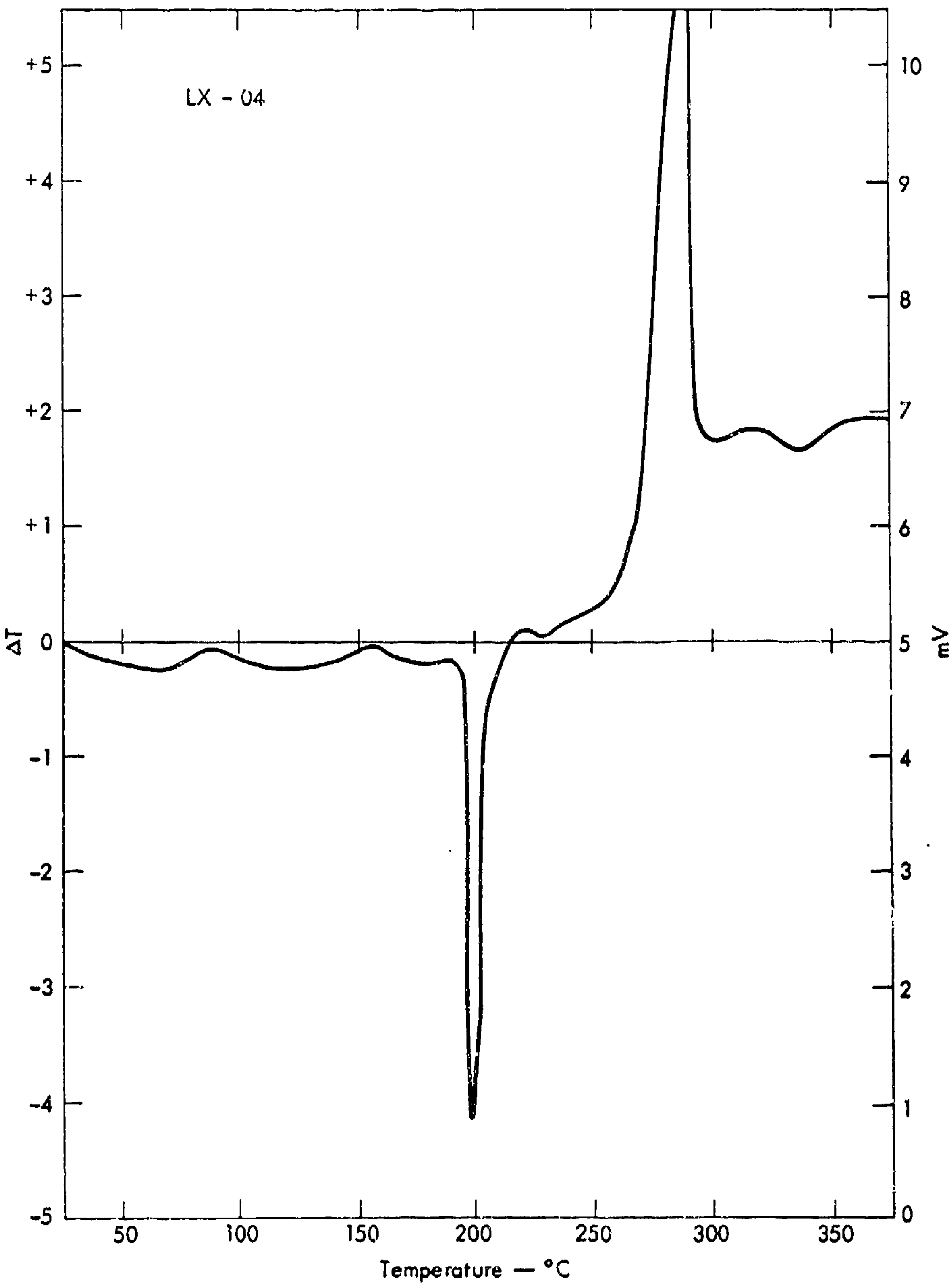


Fig. 6-6dd. DTA curve for LX-04.[47]

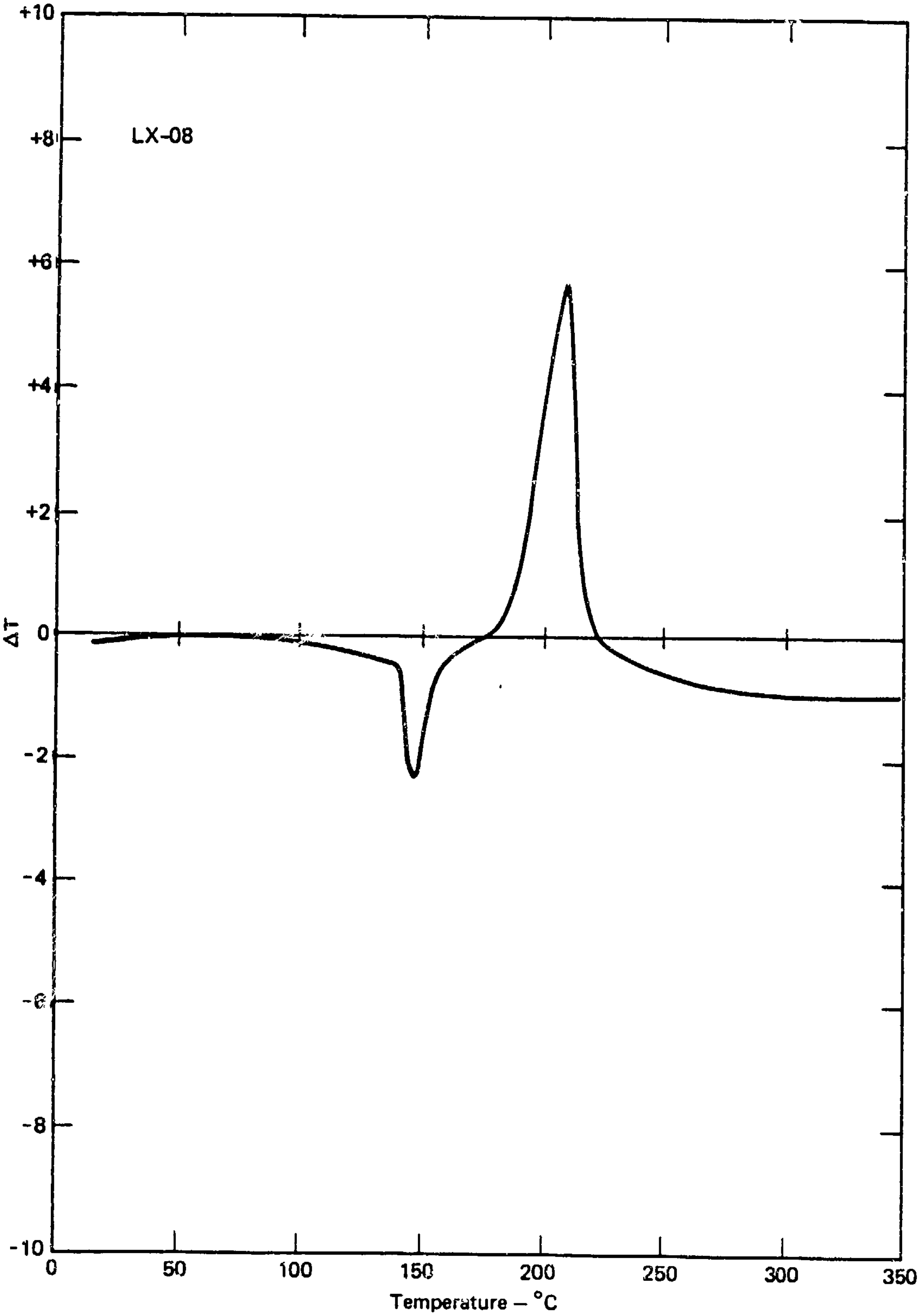


Fig. 6-6ee. DTA curve for LX-08.[46]

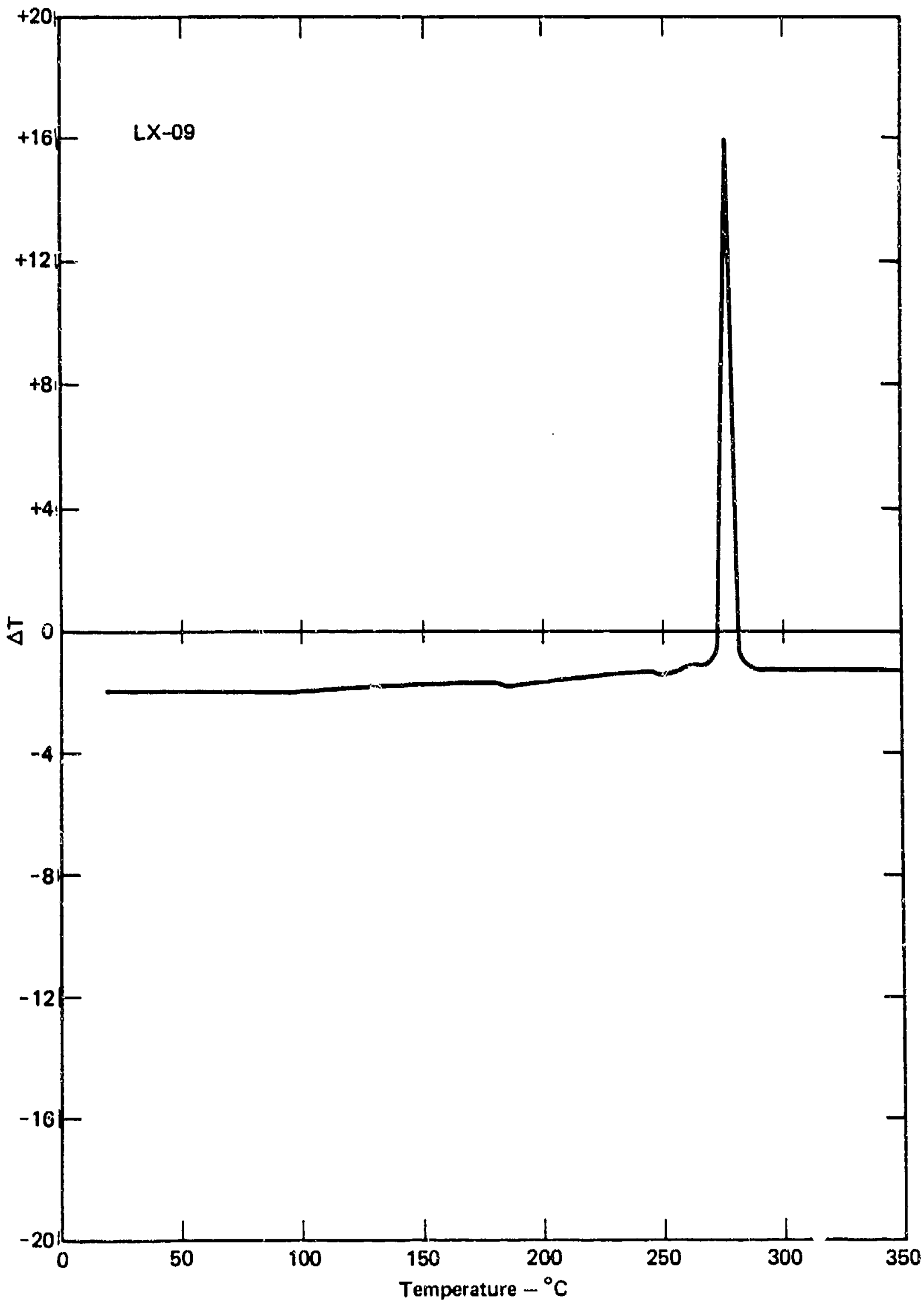


Fig. 6-6ff. DTA curve for LX-09.[46]

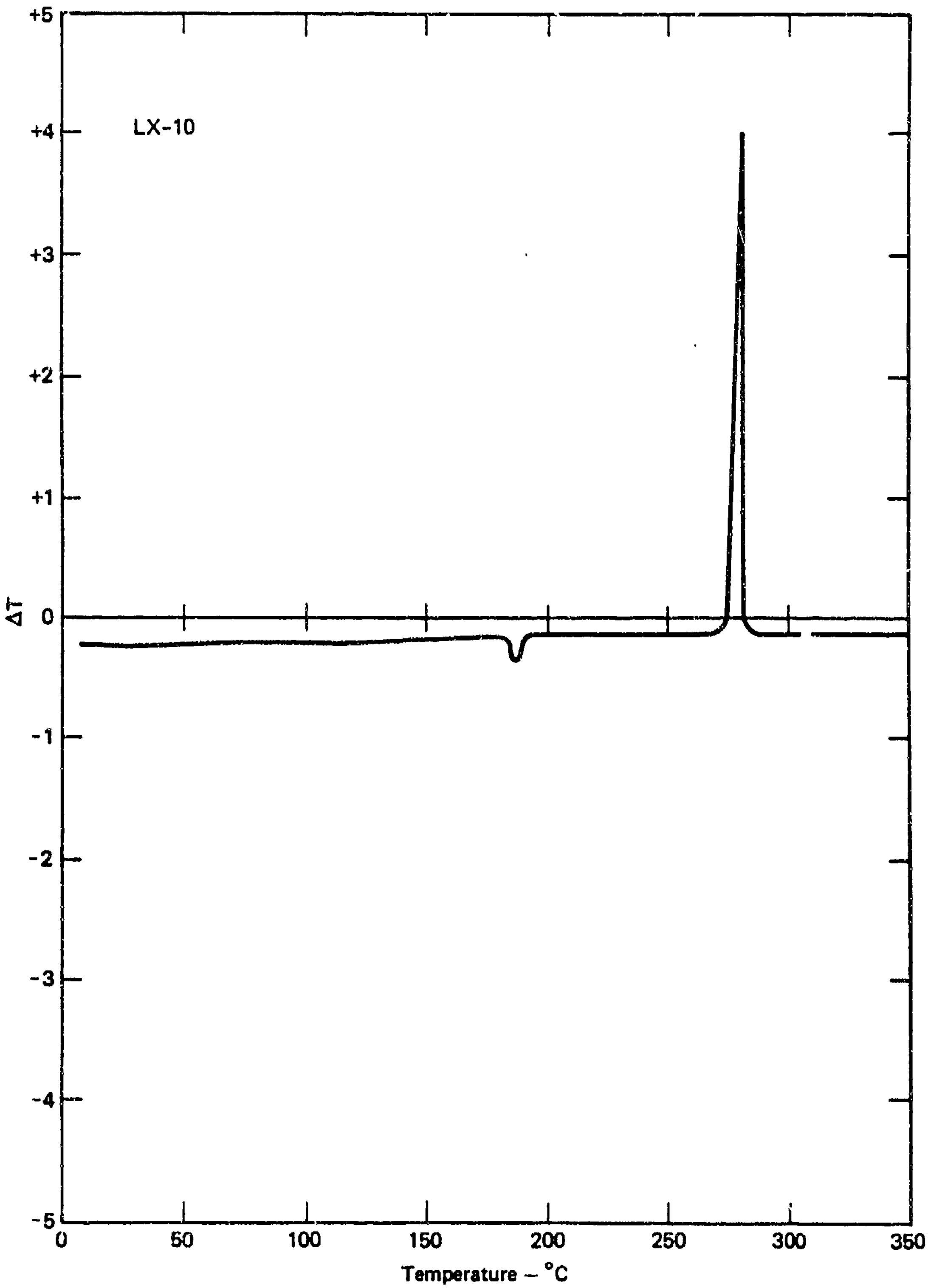


Fig. 6-6gg. DTA curve for LX-10.[46]

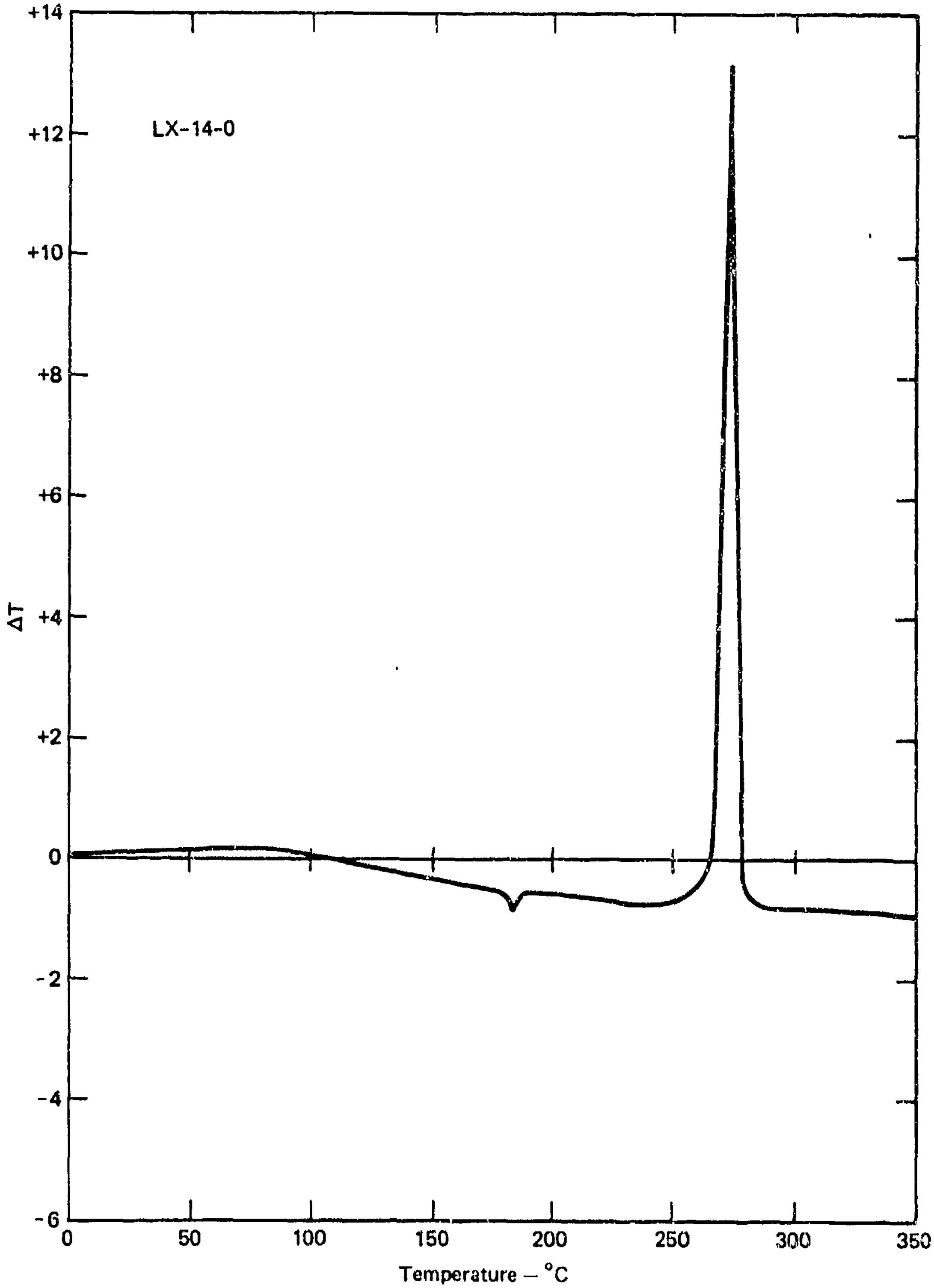


Fig. 6-6hh. DTA curve for LX-14.[46]

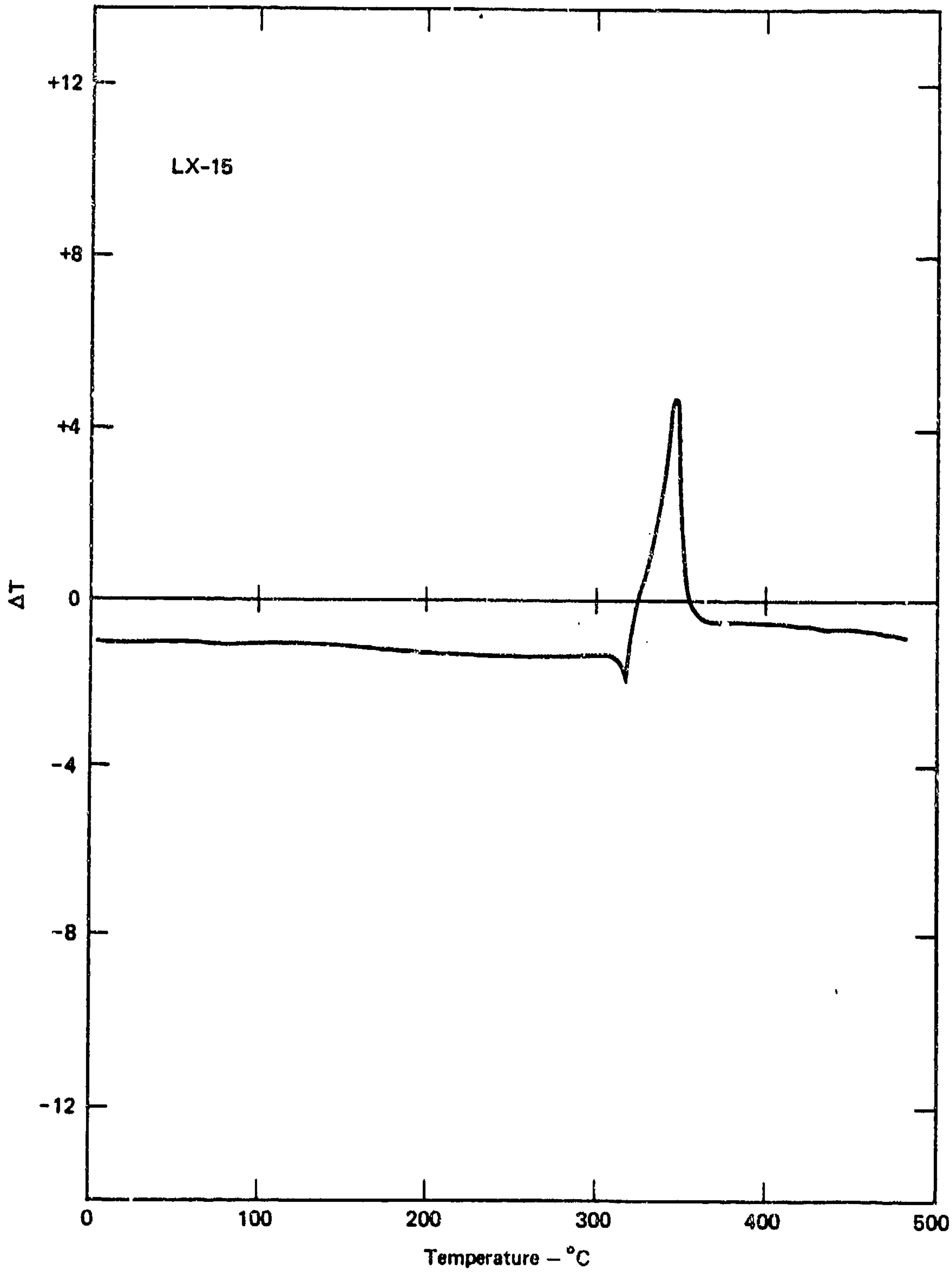


Fig. 6-6ii. DTA curve for LX-15.[46]

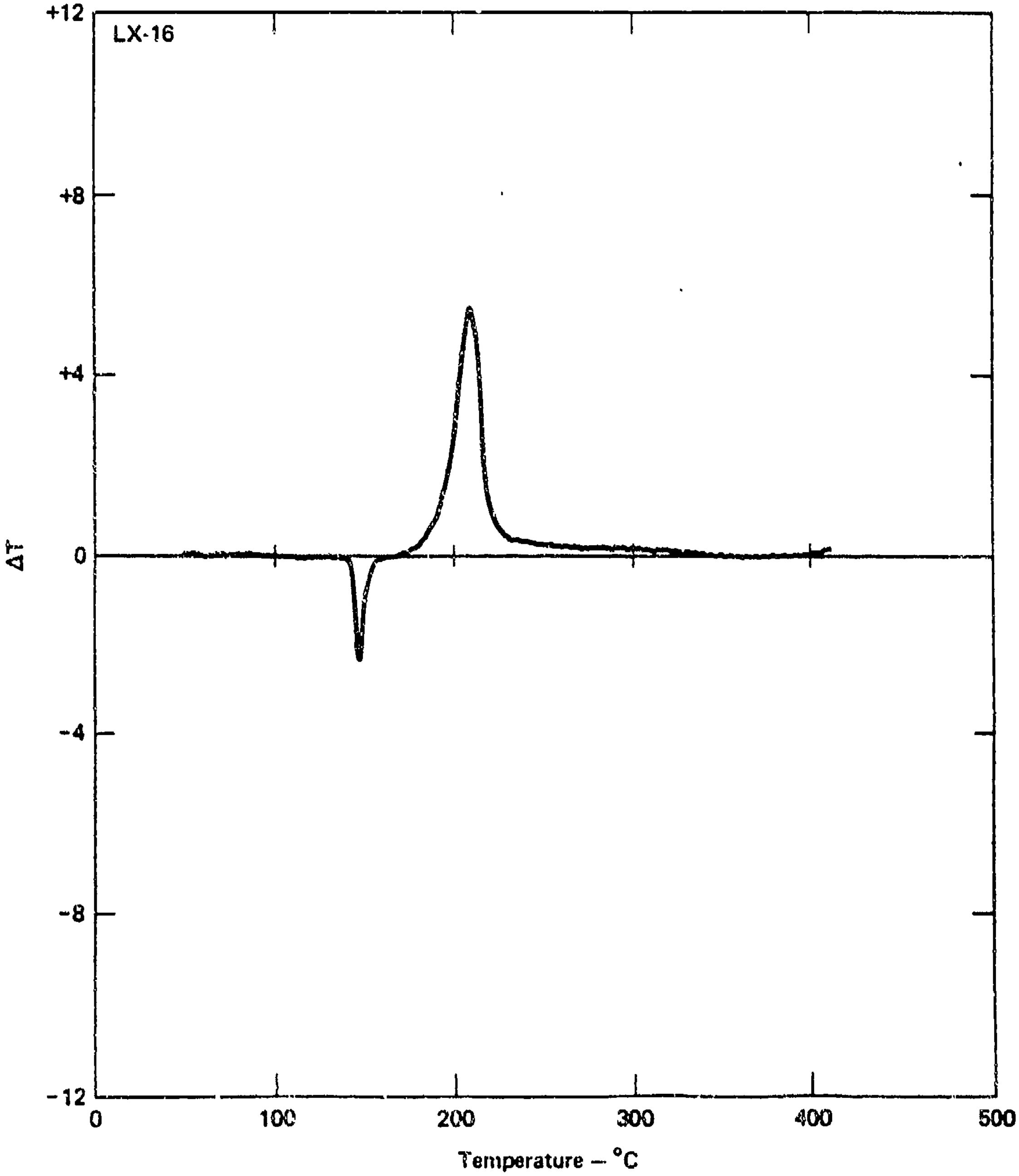


Fig. 6-6jj. DTA curve for LX-16.[46]

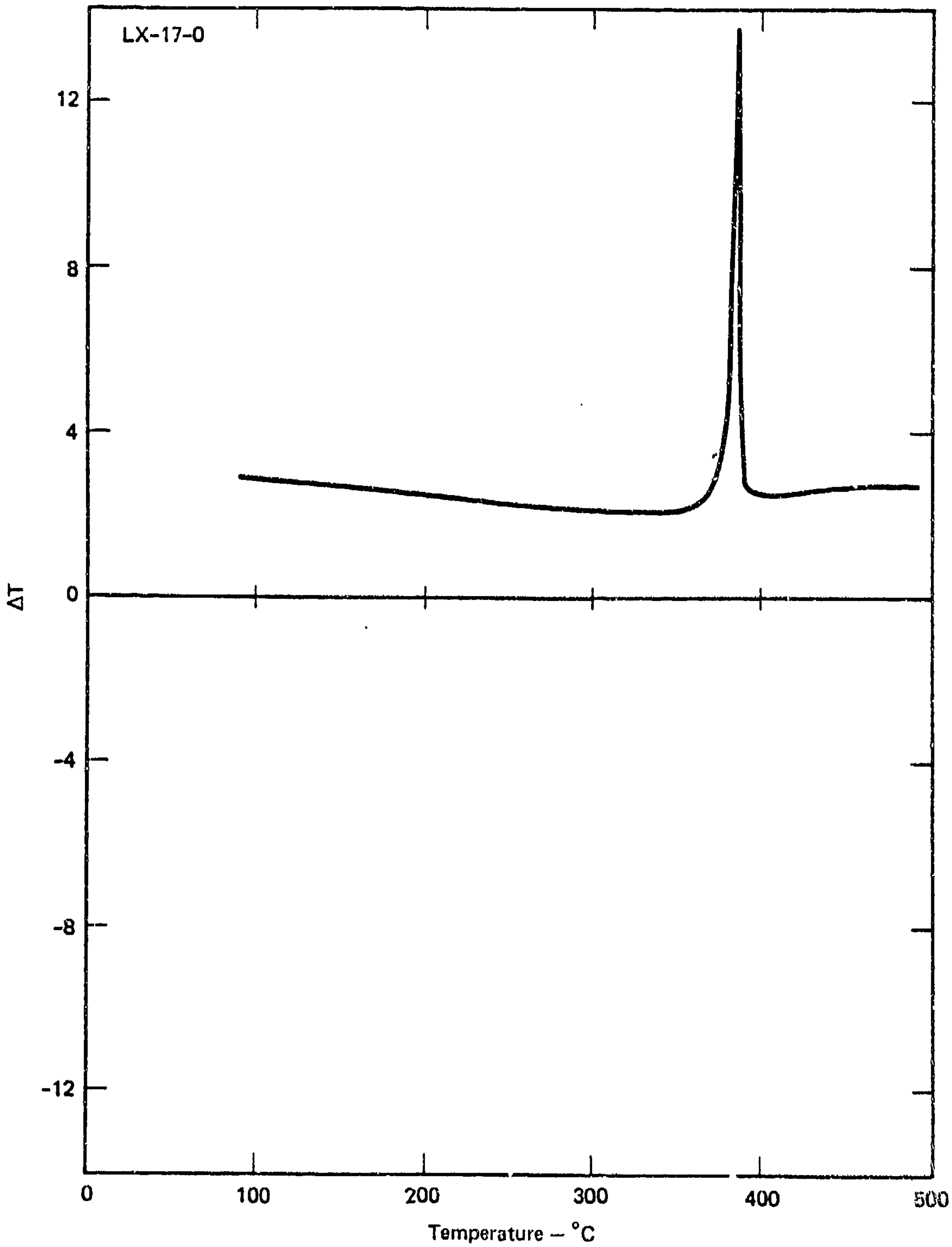


Fig. 6-6kk. DTA curve for LX-17.[46]

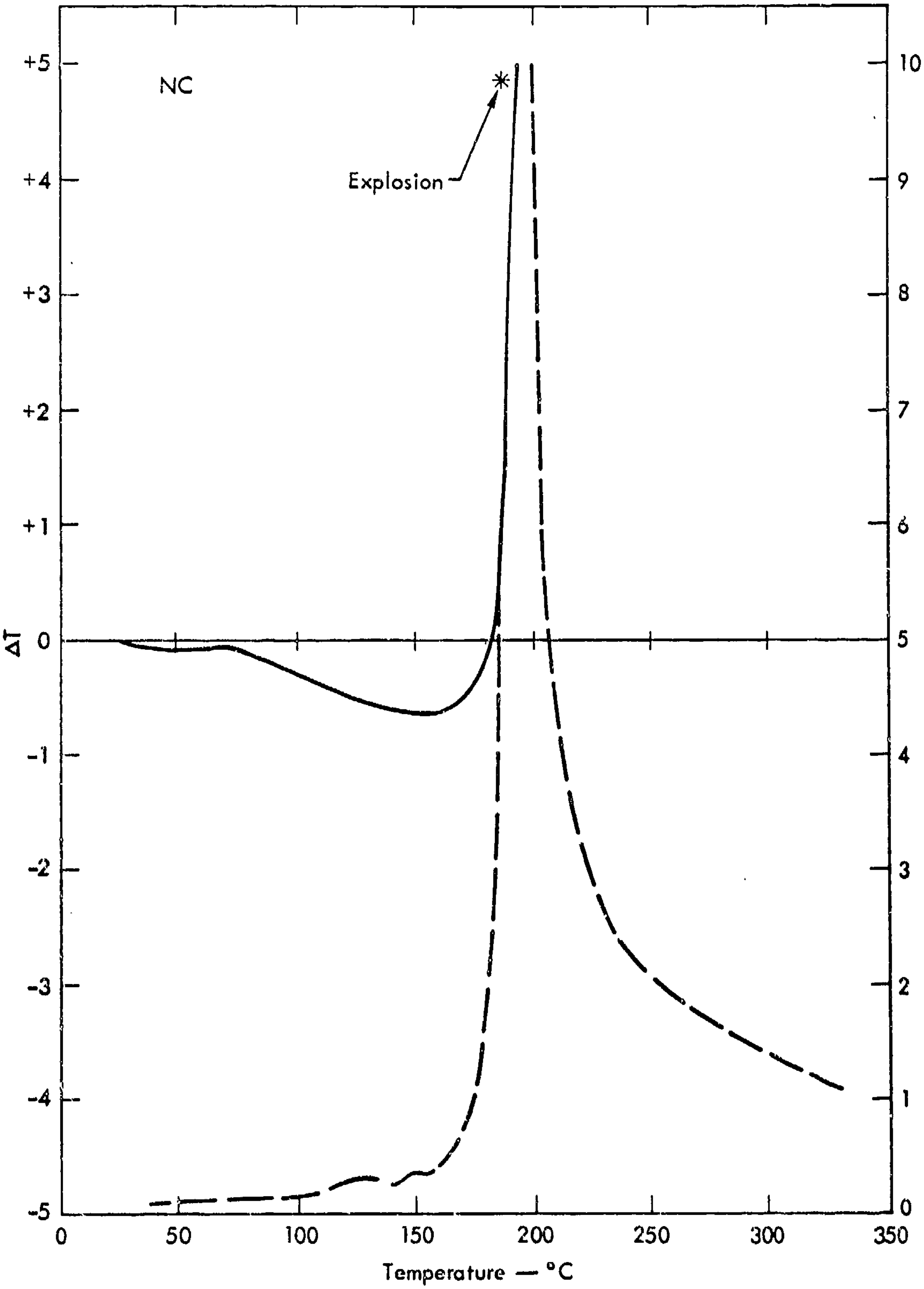


Fig. 6-611. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for NC.[47]

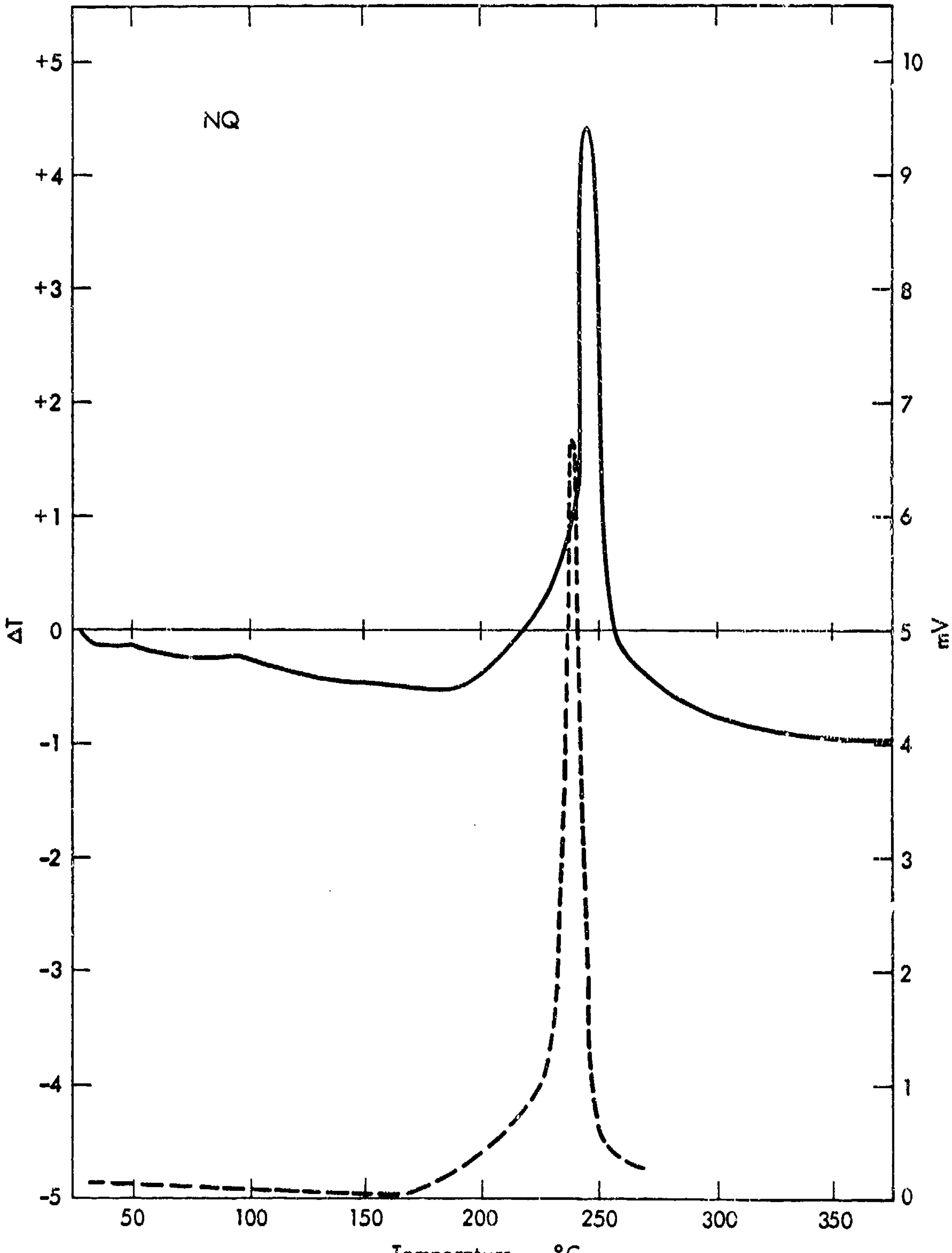


Fig. 6-6mm. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for NQ.[47]

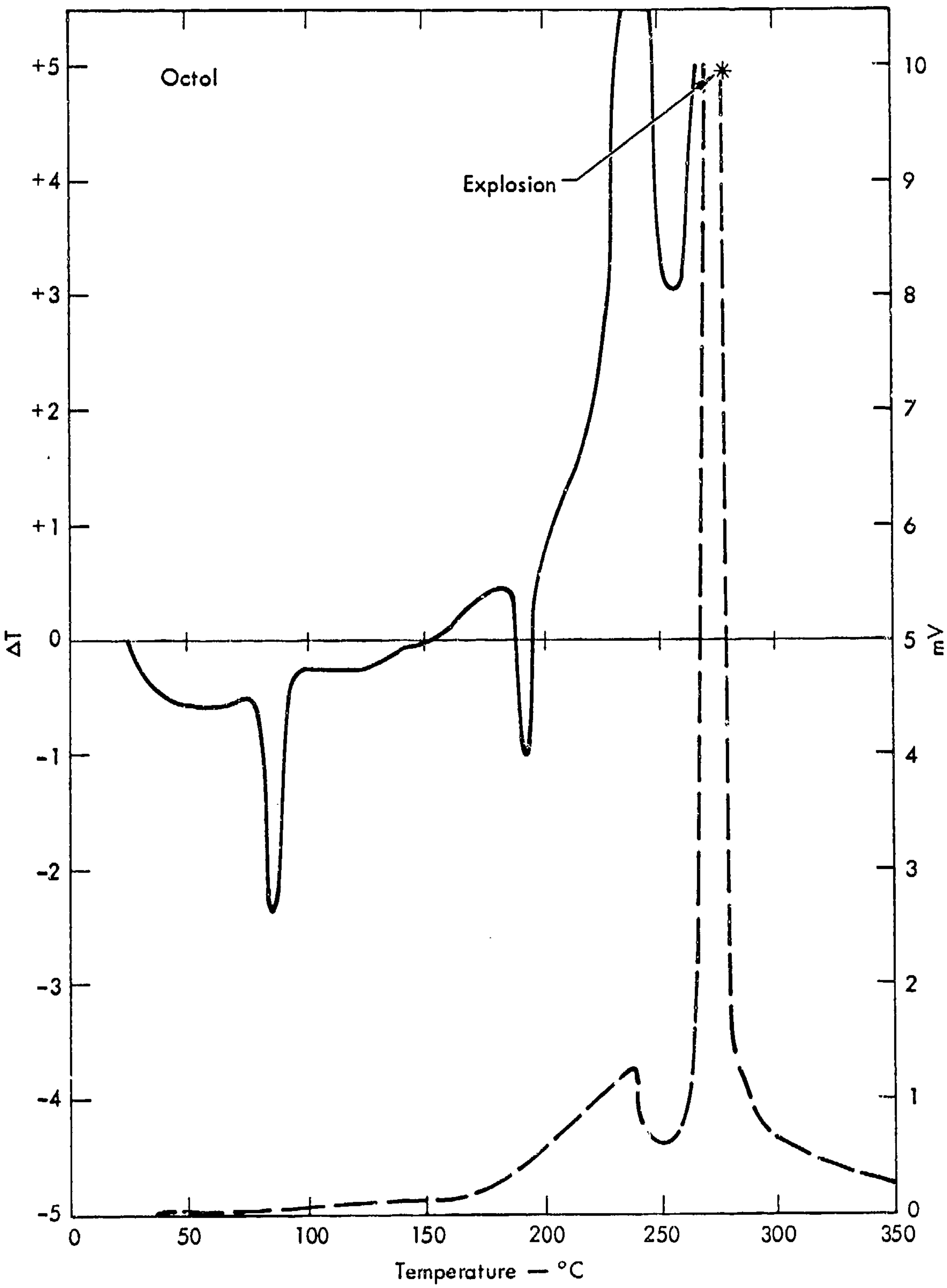


Fig. 6-6nn. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Octol.[47]

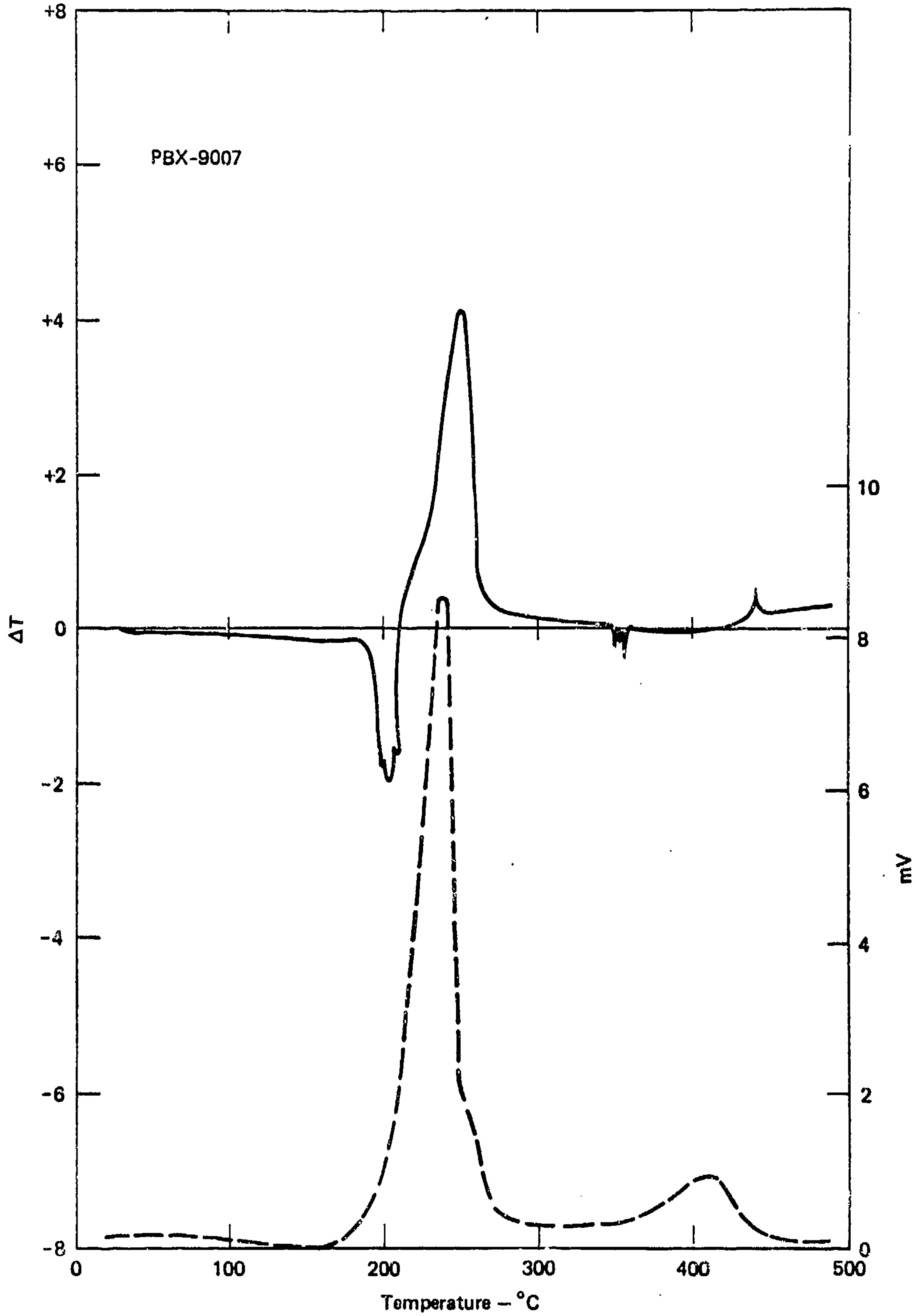


Fig. 6-600. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for PBX-9007.[47]

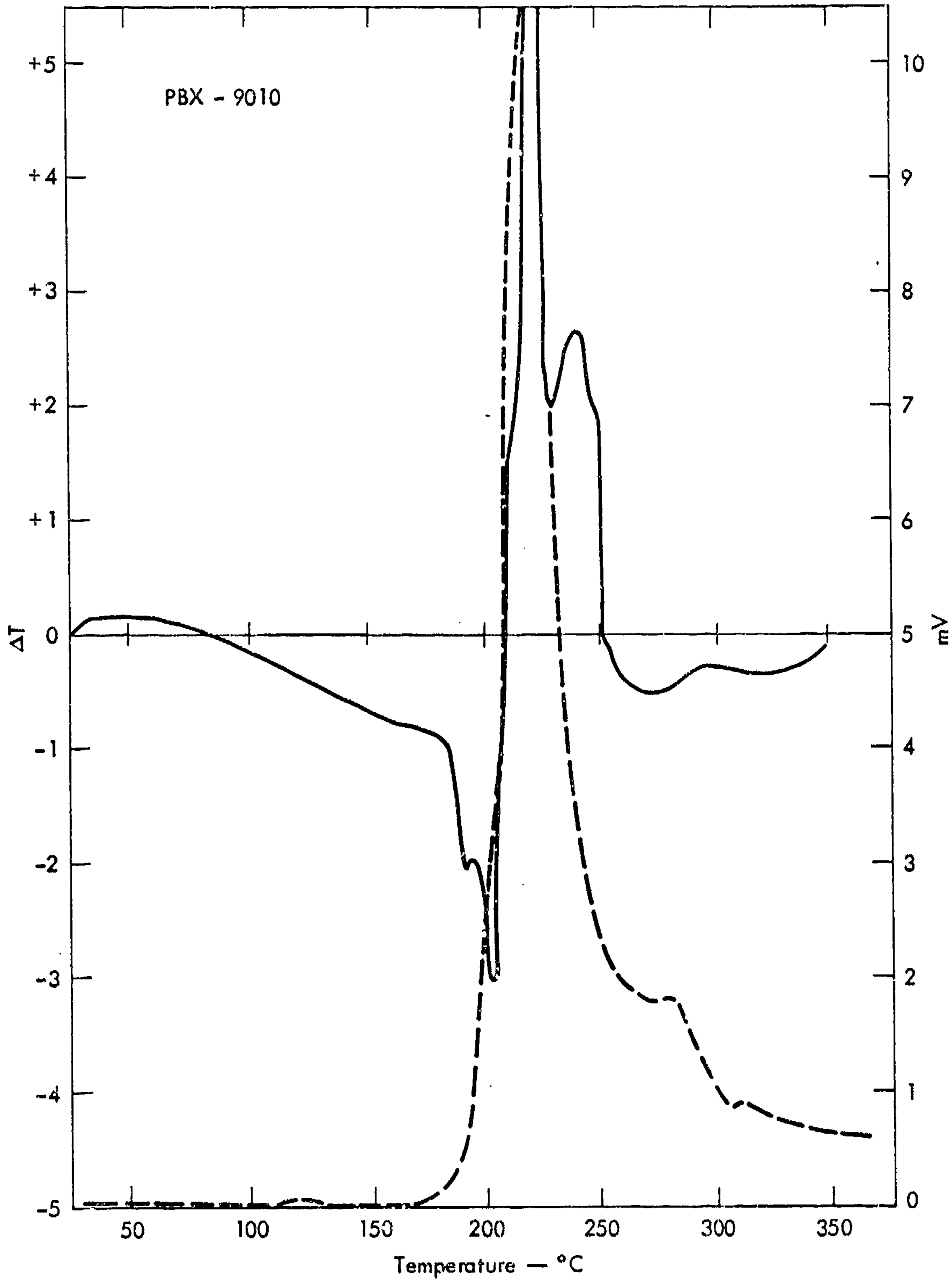


Fig. 6-6pp. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for PBX-9010.[47]

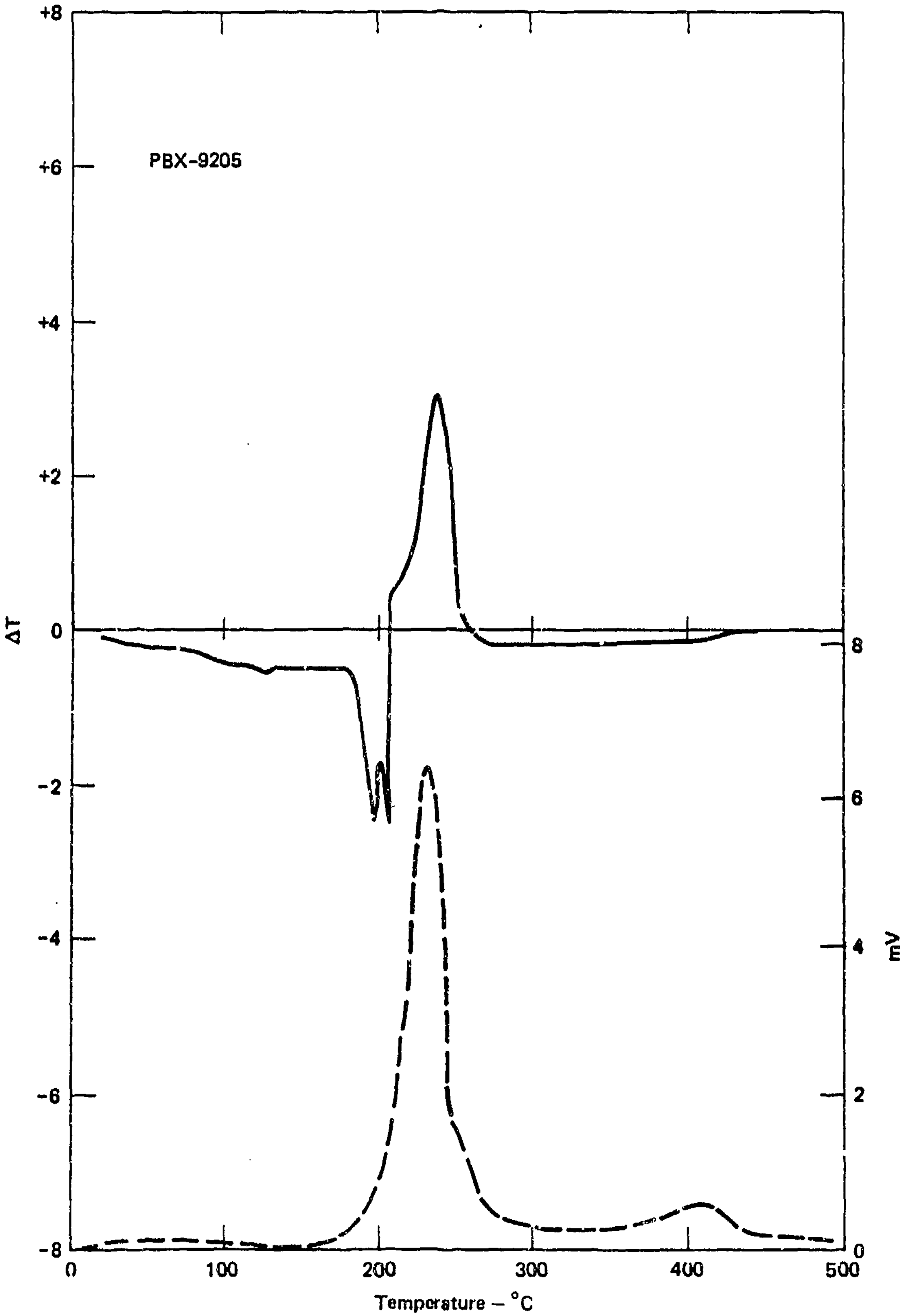


Fig. 6-6qq. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for PBX-9205.[47]

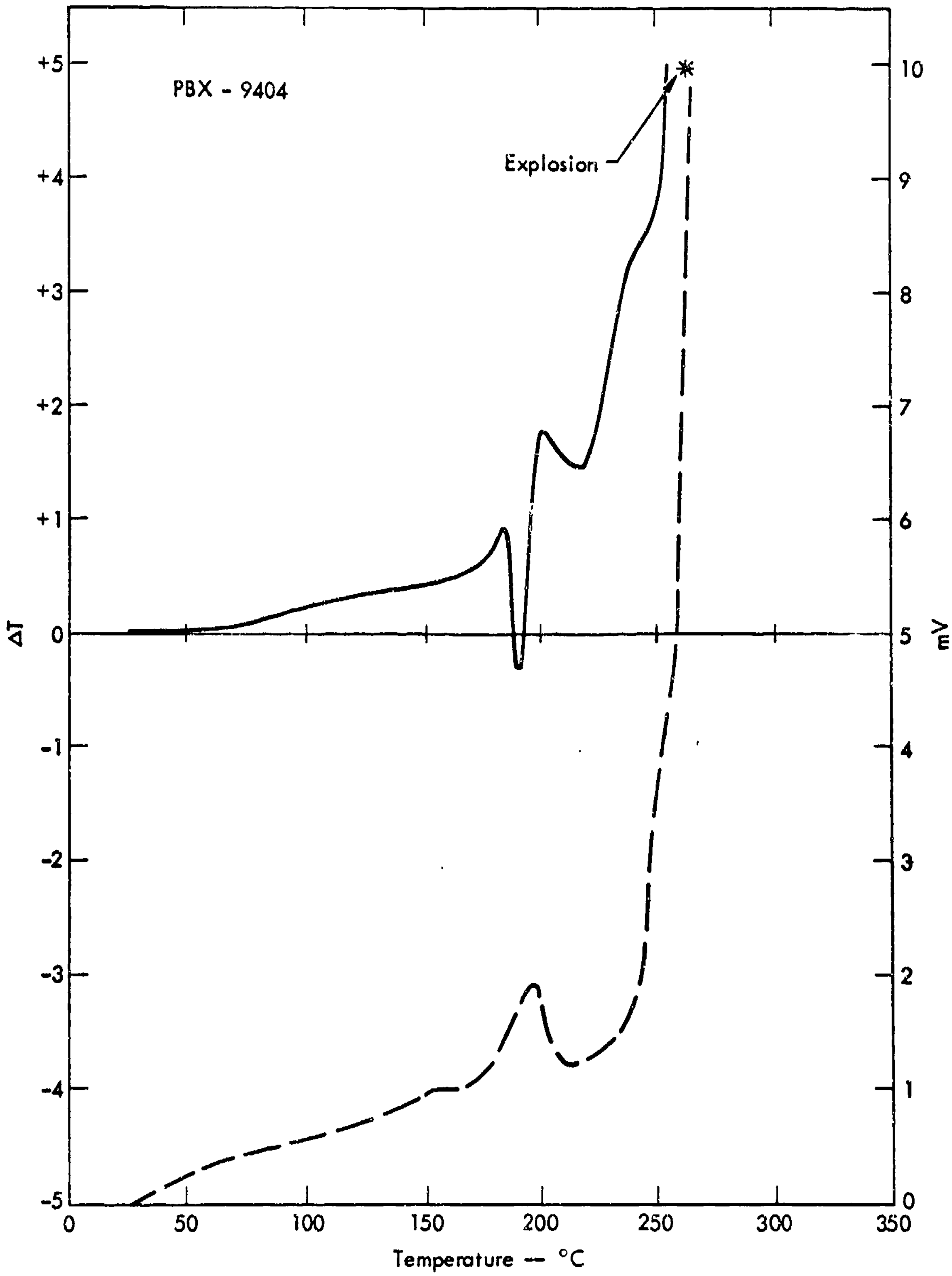


Fig. 6-6rr. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for PBX-9404.[47]

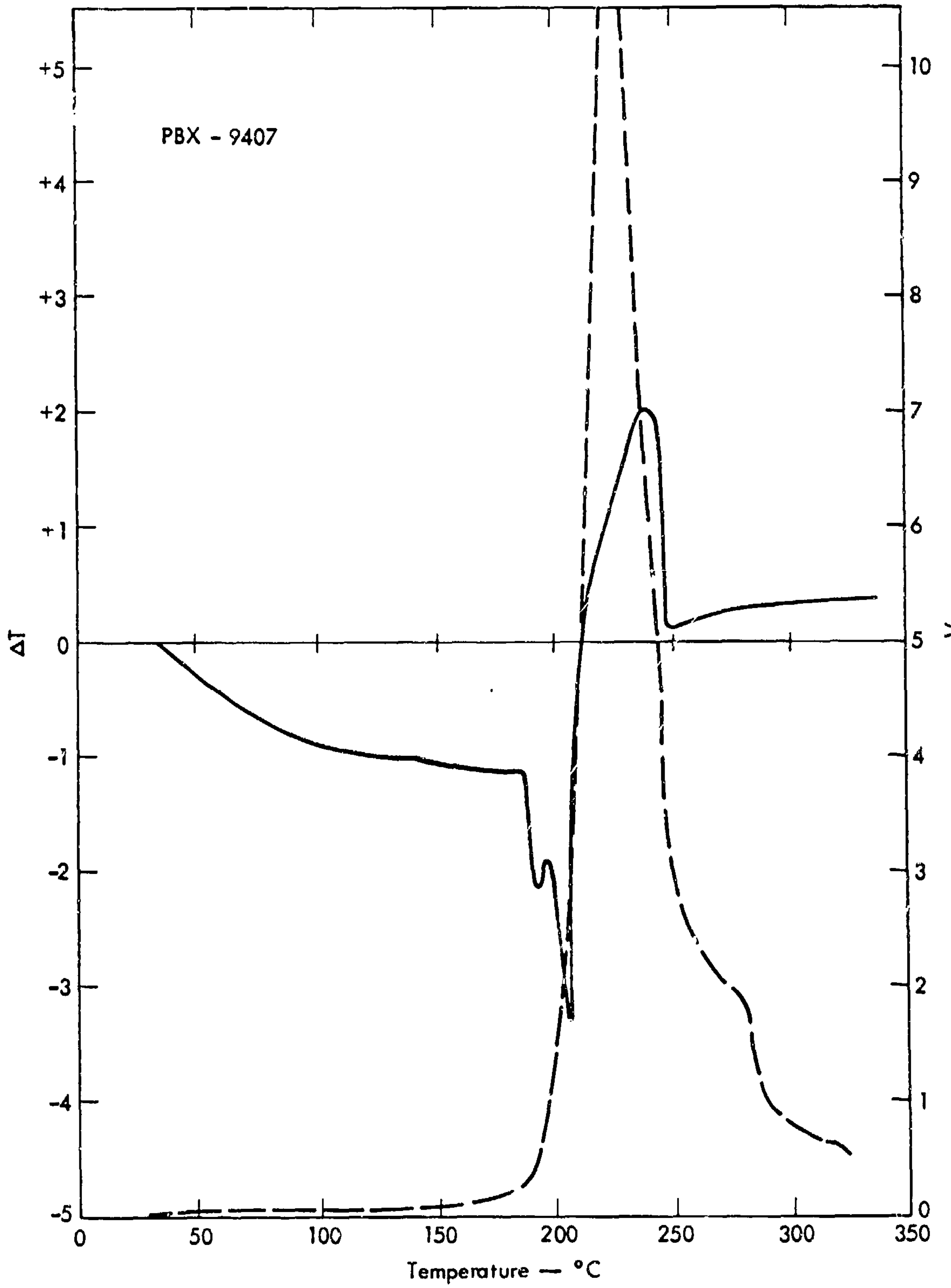


Fig. 6-6ss. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for PBX-9407.[47]

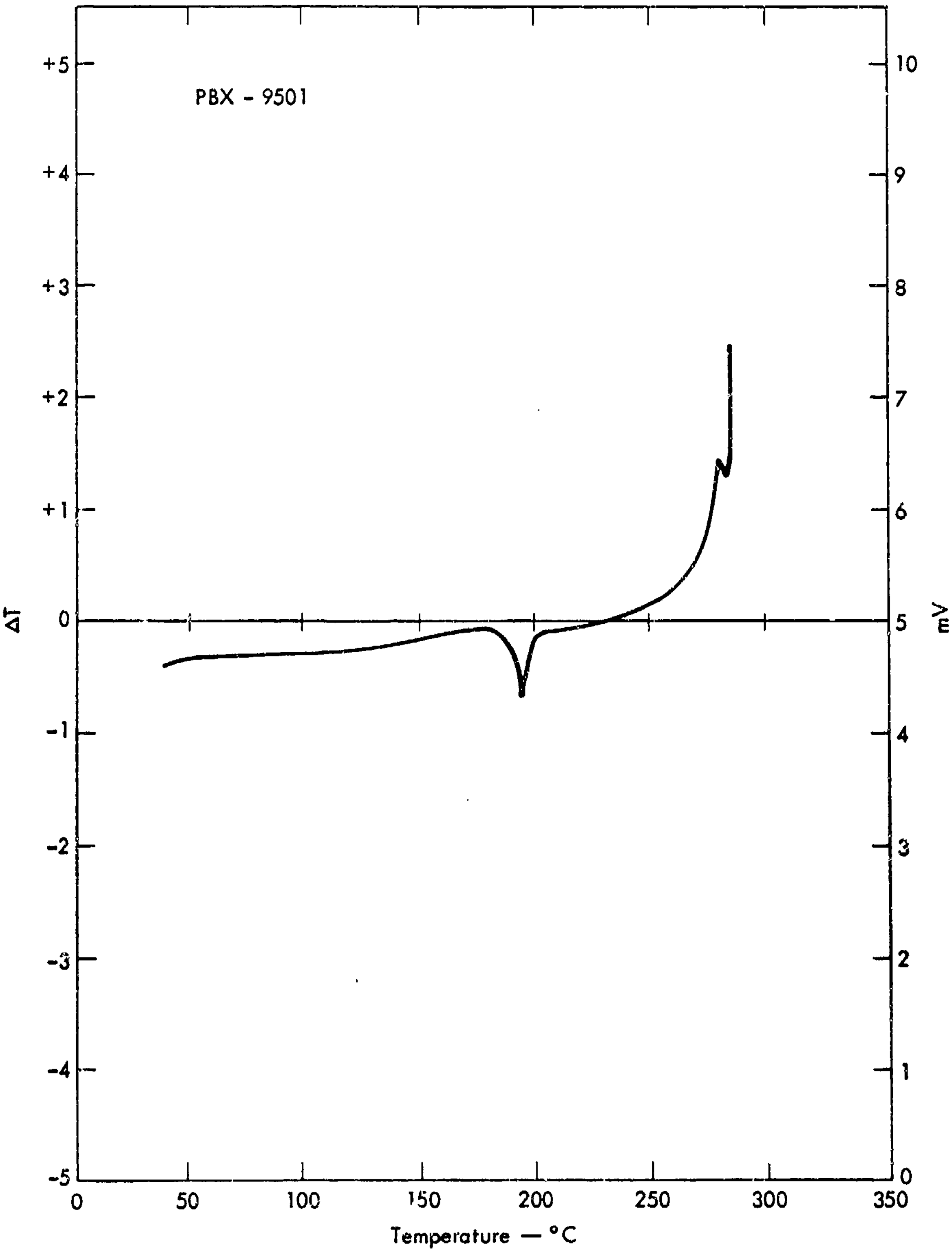


Fig. 6-6tt. DTA curve for PBX-9501.[47]

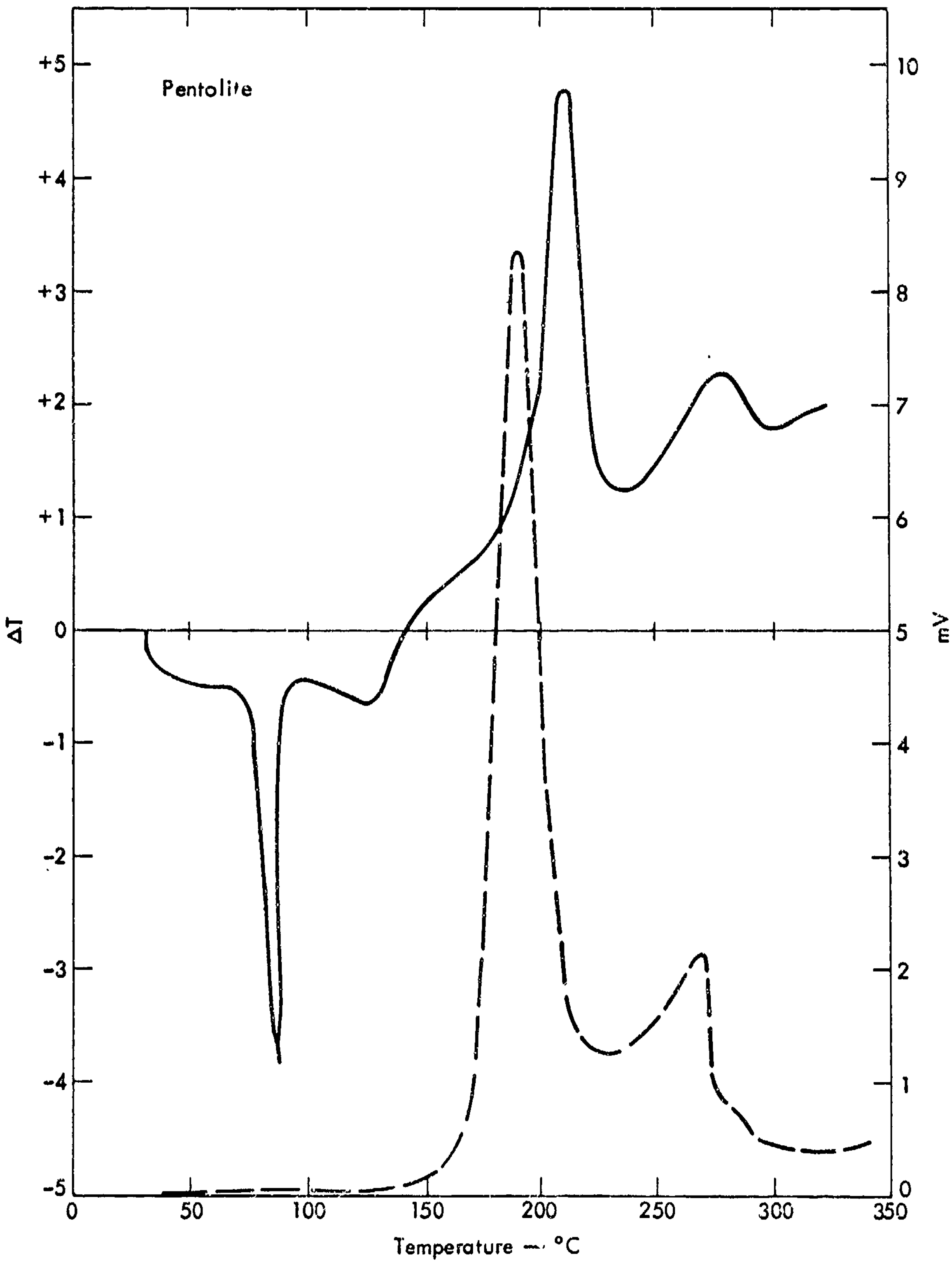


Fig. 6-6uu. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Pentolite.[47]

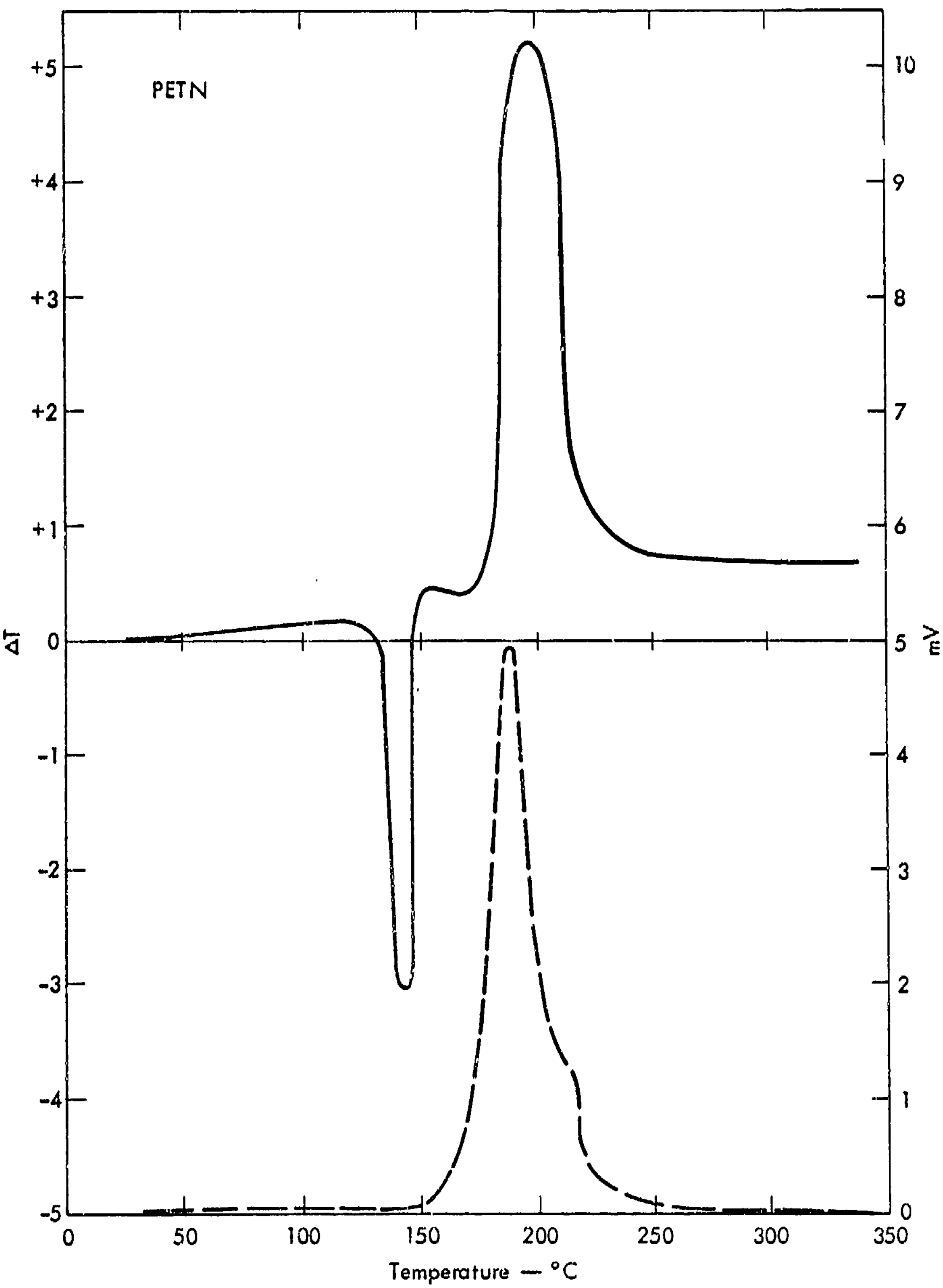


Fig. 6-6vv. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for PETN.[47]

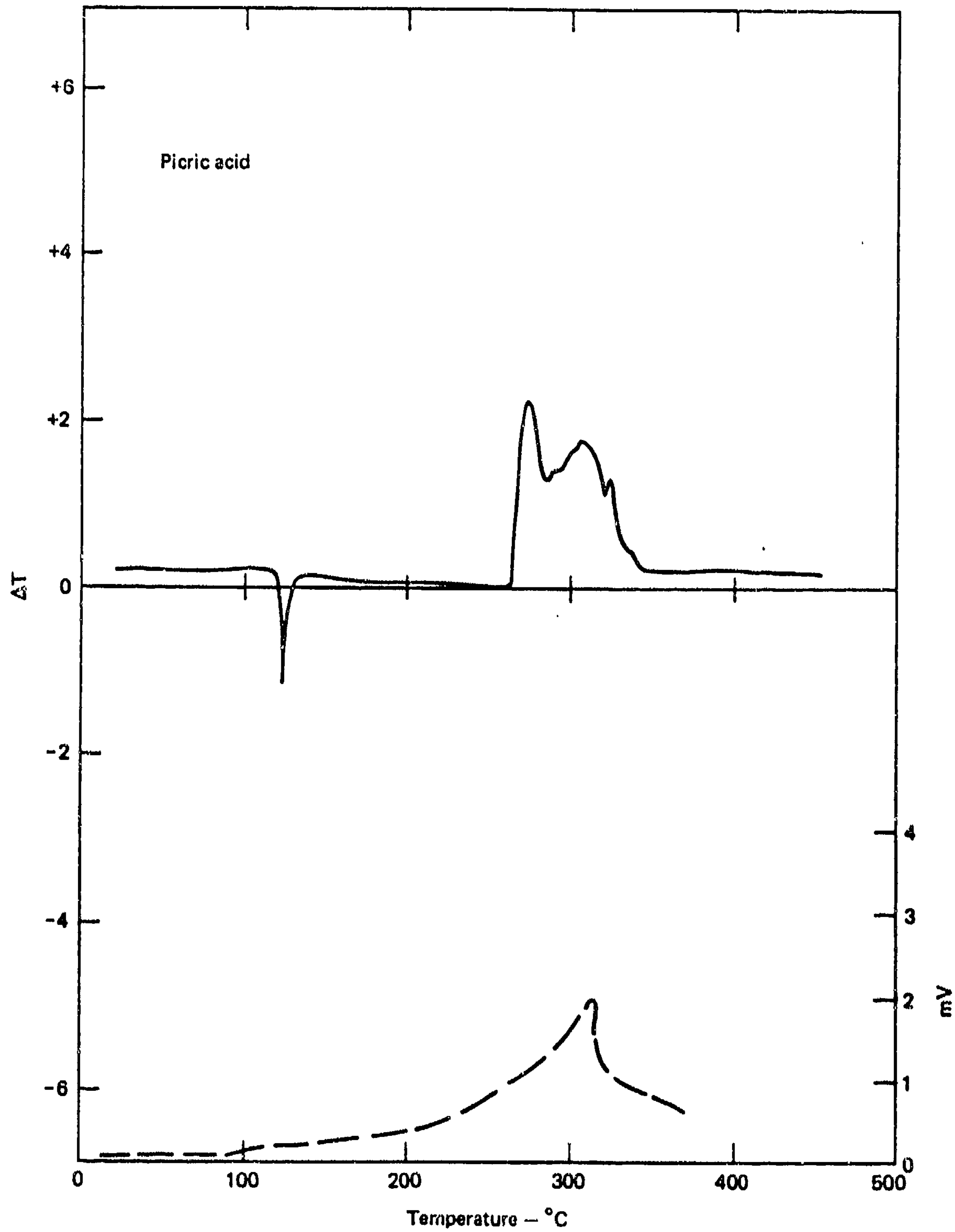


Fig. 6-6ww. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for picric acid.[46,47]

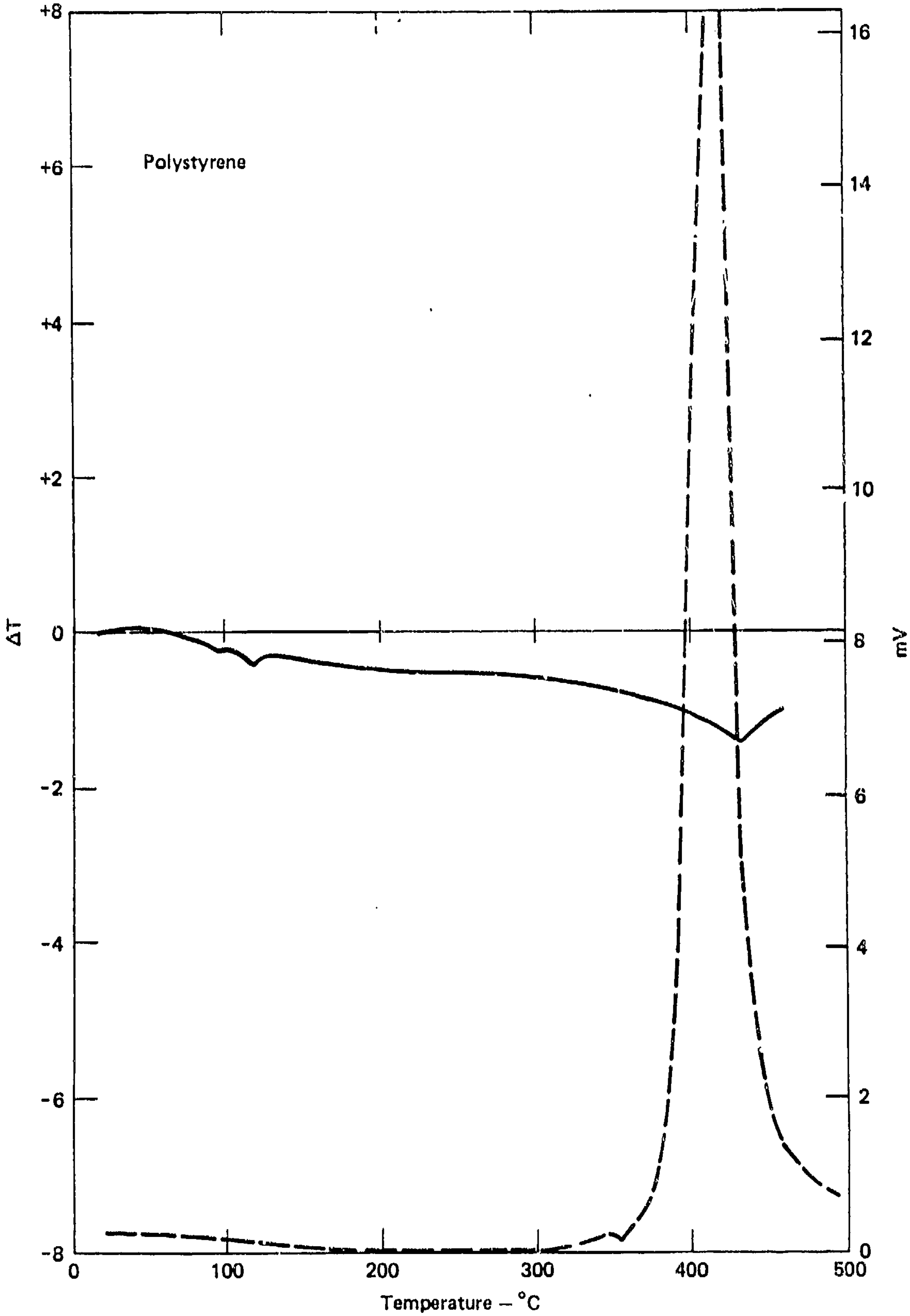


Fig. 6-6xx. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for polystyrene.[47]

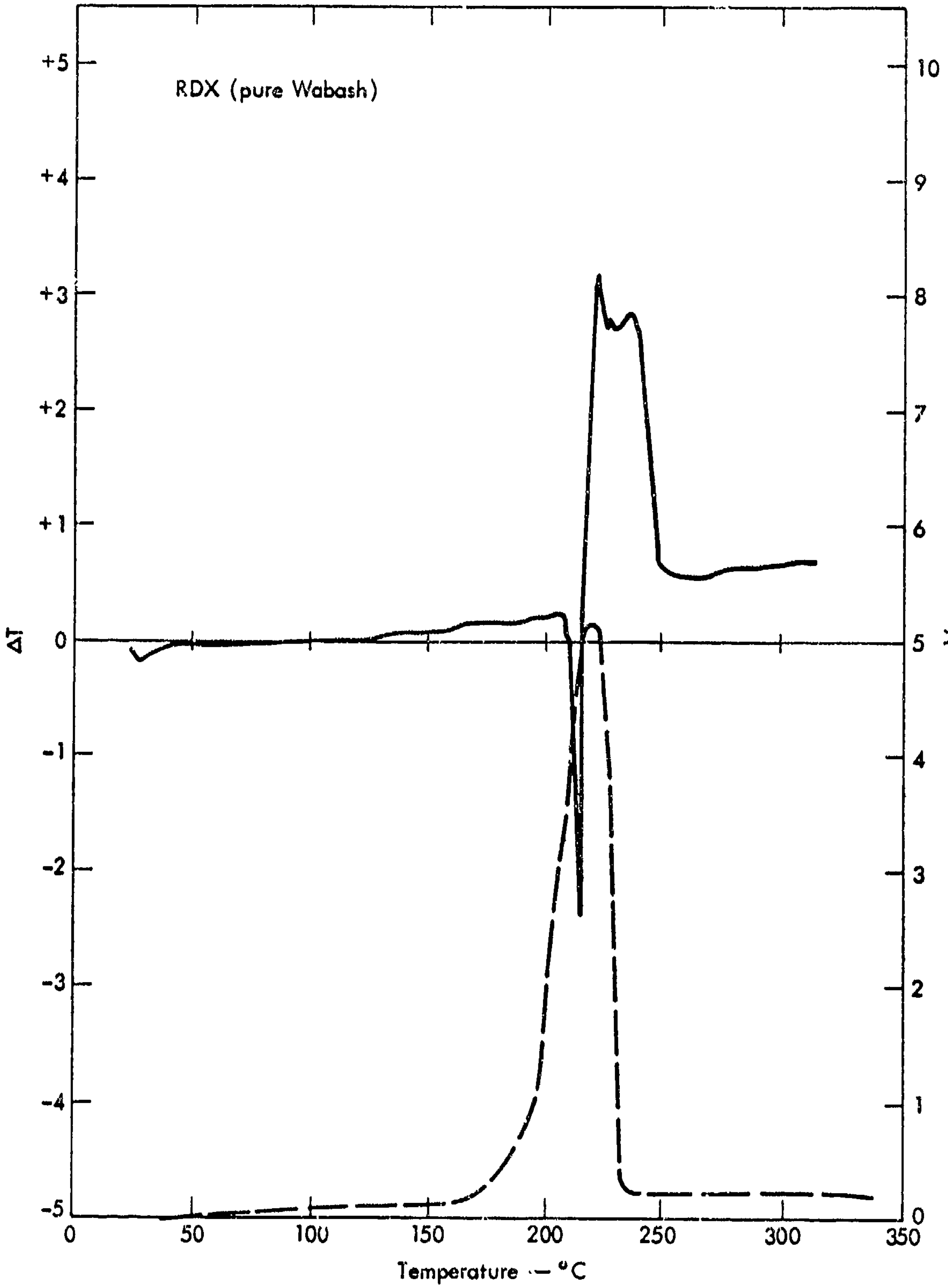


Fig. 6-6yy. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for RDX (pure Wabash grade).[47]

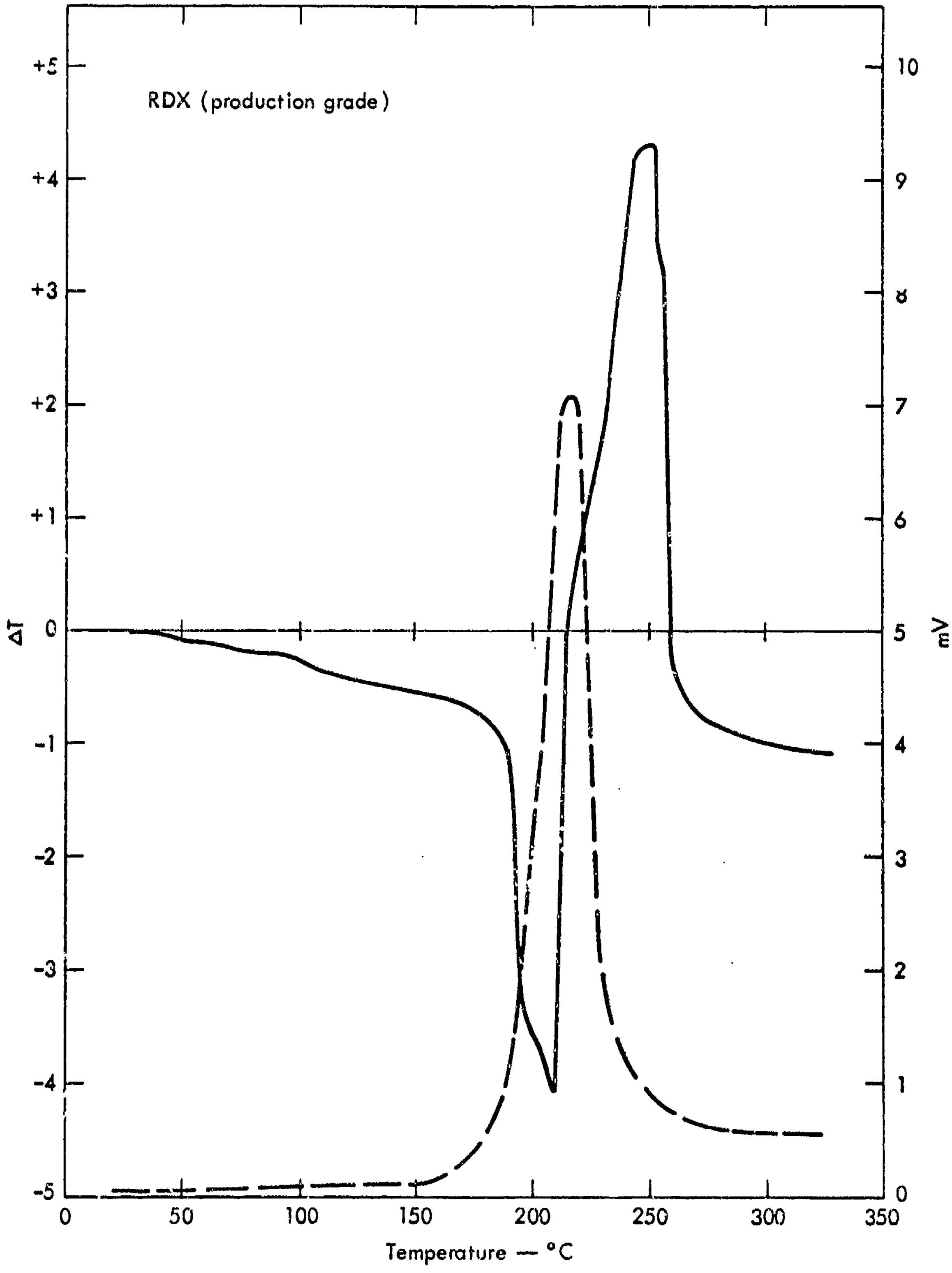


Fig. 6-6zz. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for RDX (Holston production grade).[47]

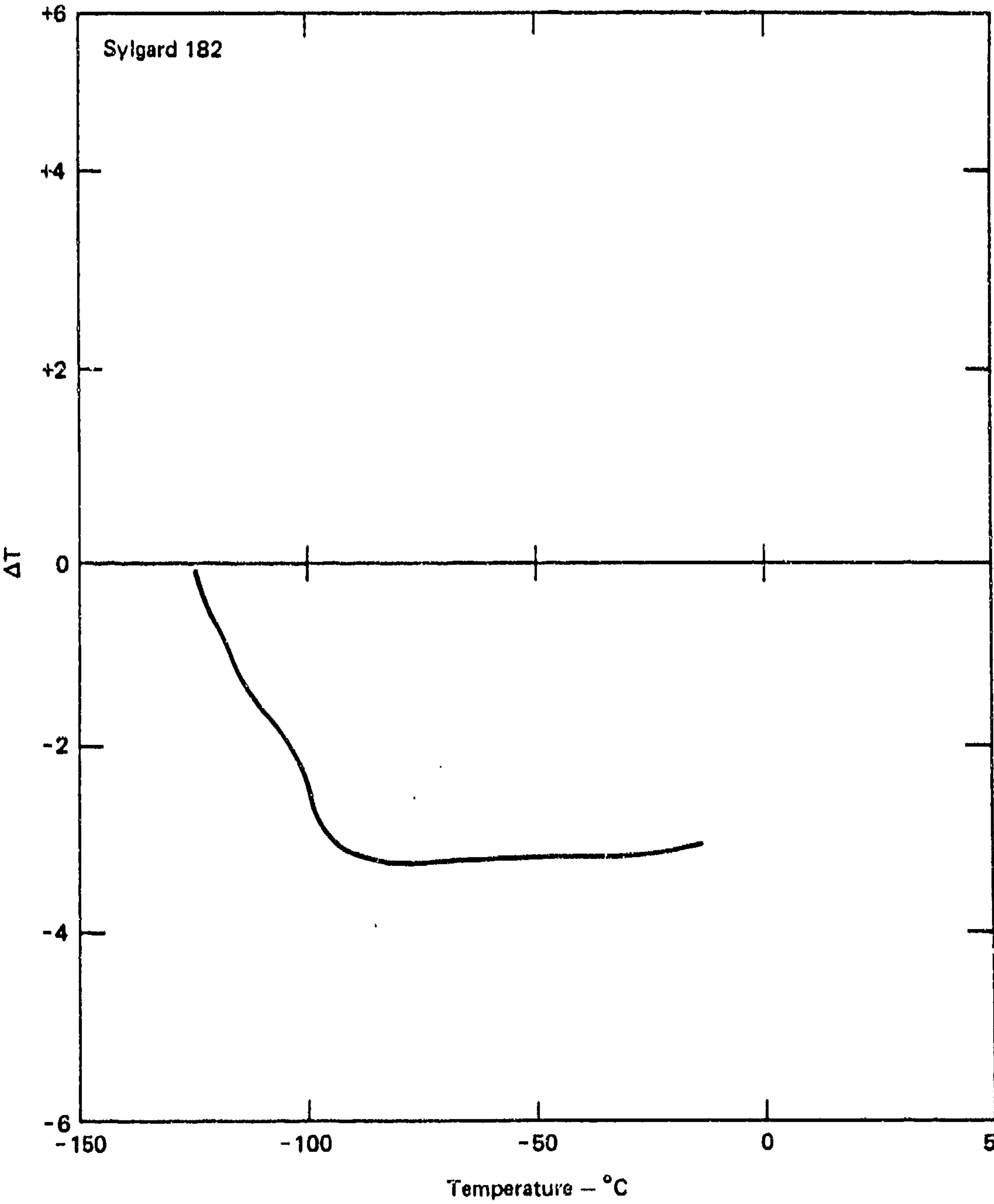


Fig. 6-6aaa. DTA curve for Sylgard 182.[46]

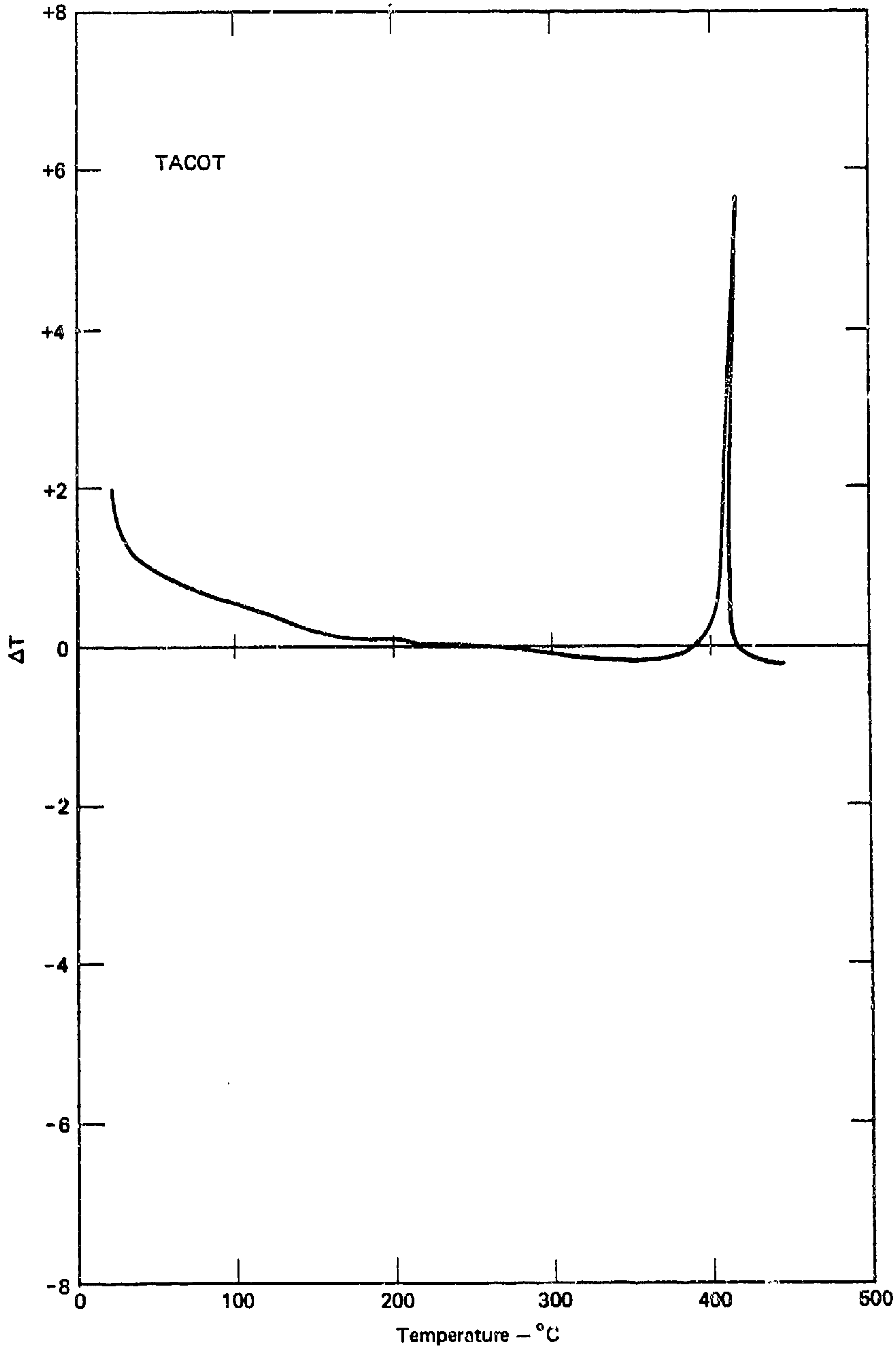


Fig. 6-6bbb. DTA curve for TACOT.[47]

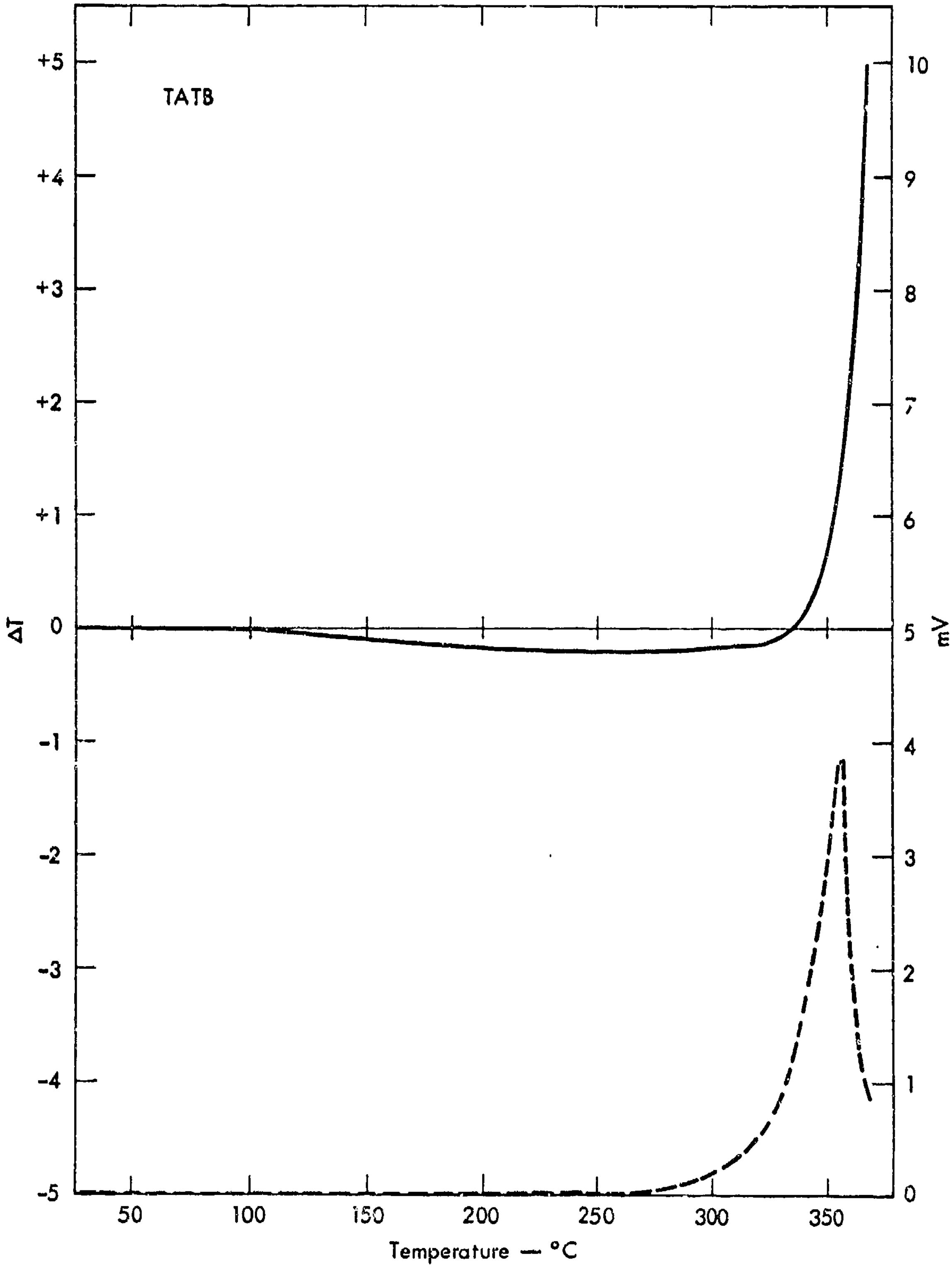


Fig. 6-6ccc. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for TATB.[47]

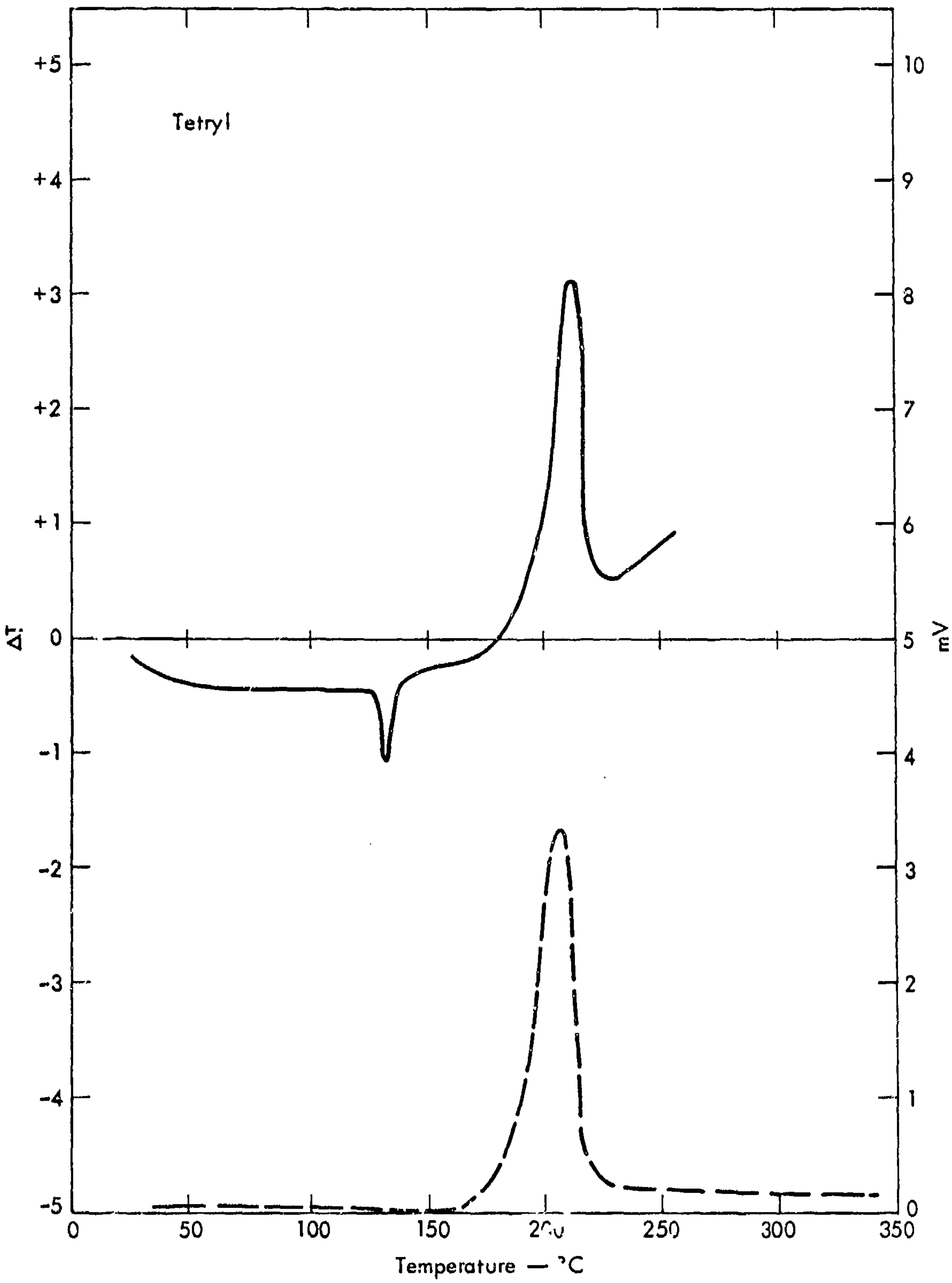


Fig. 6-6ddd. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Tetryl.[47]

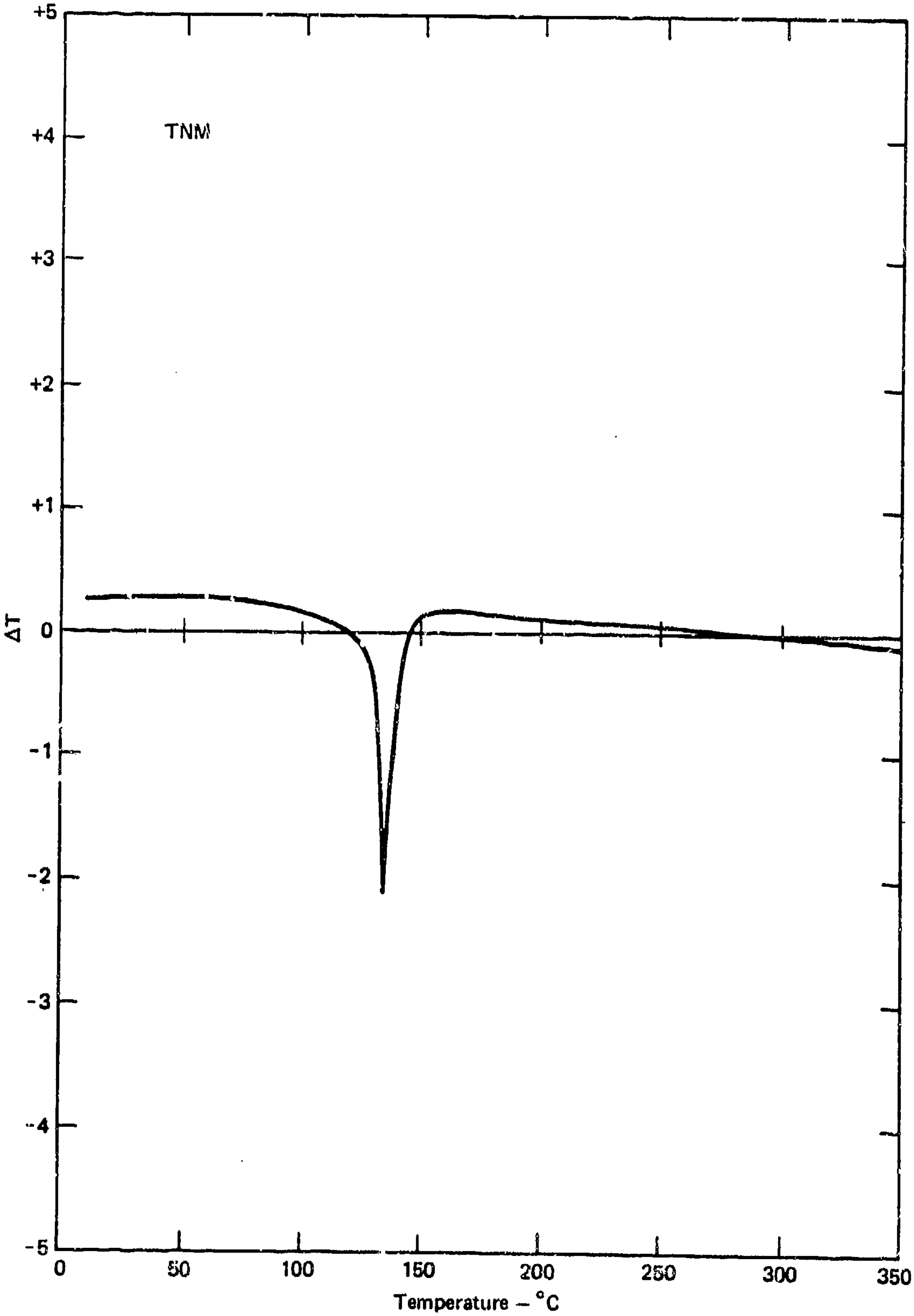


Fig. 6-6eee. DTA curve for TNM.46

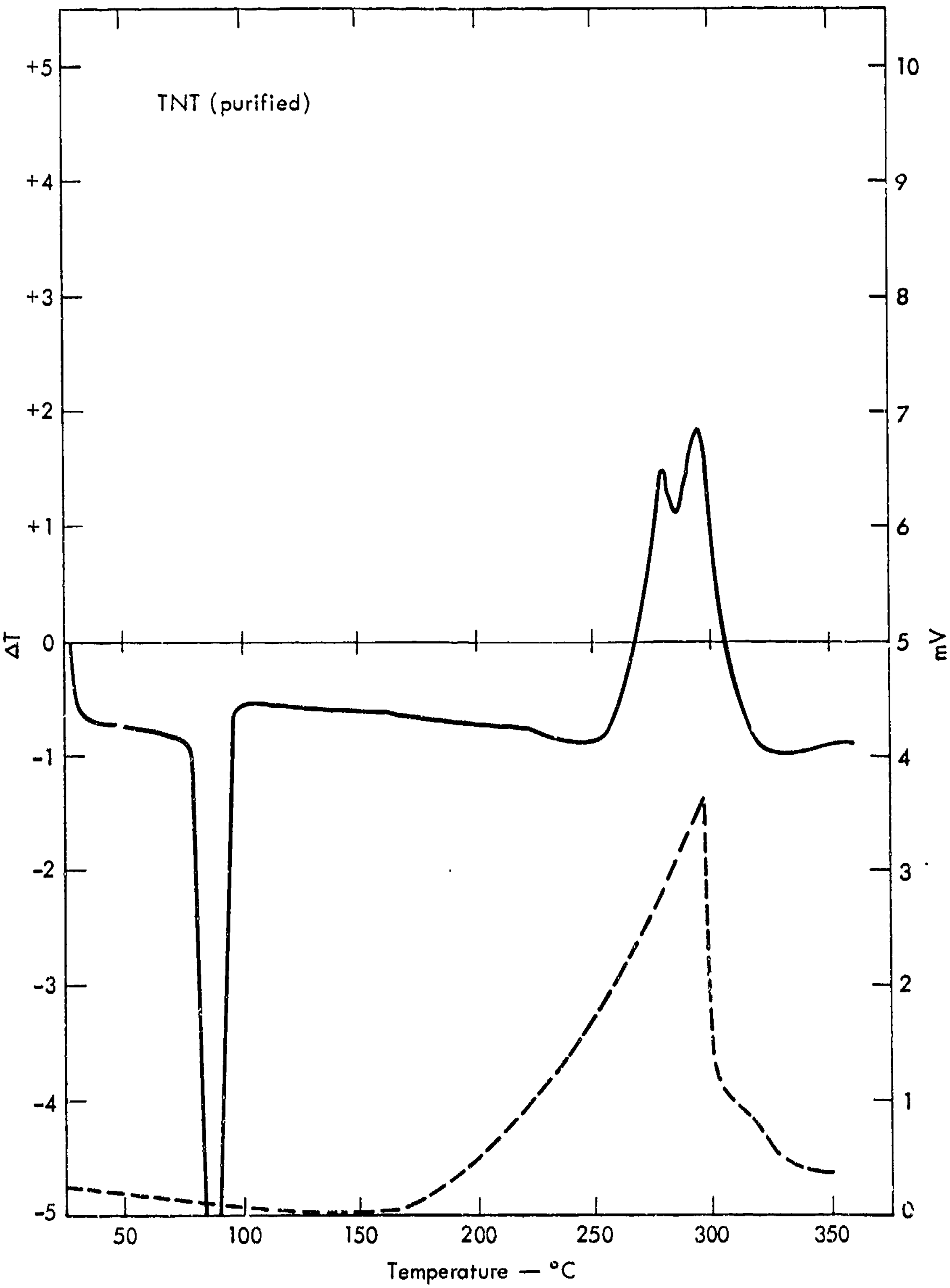


Fig. 6-6fff. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for TNT.[47]

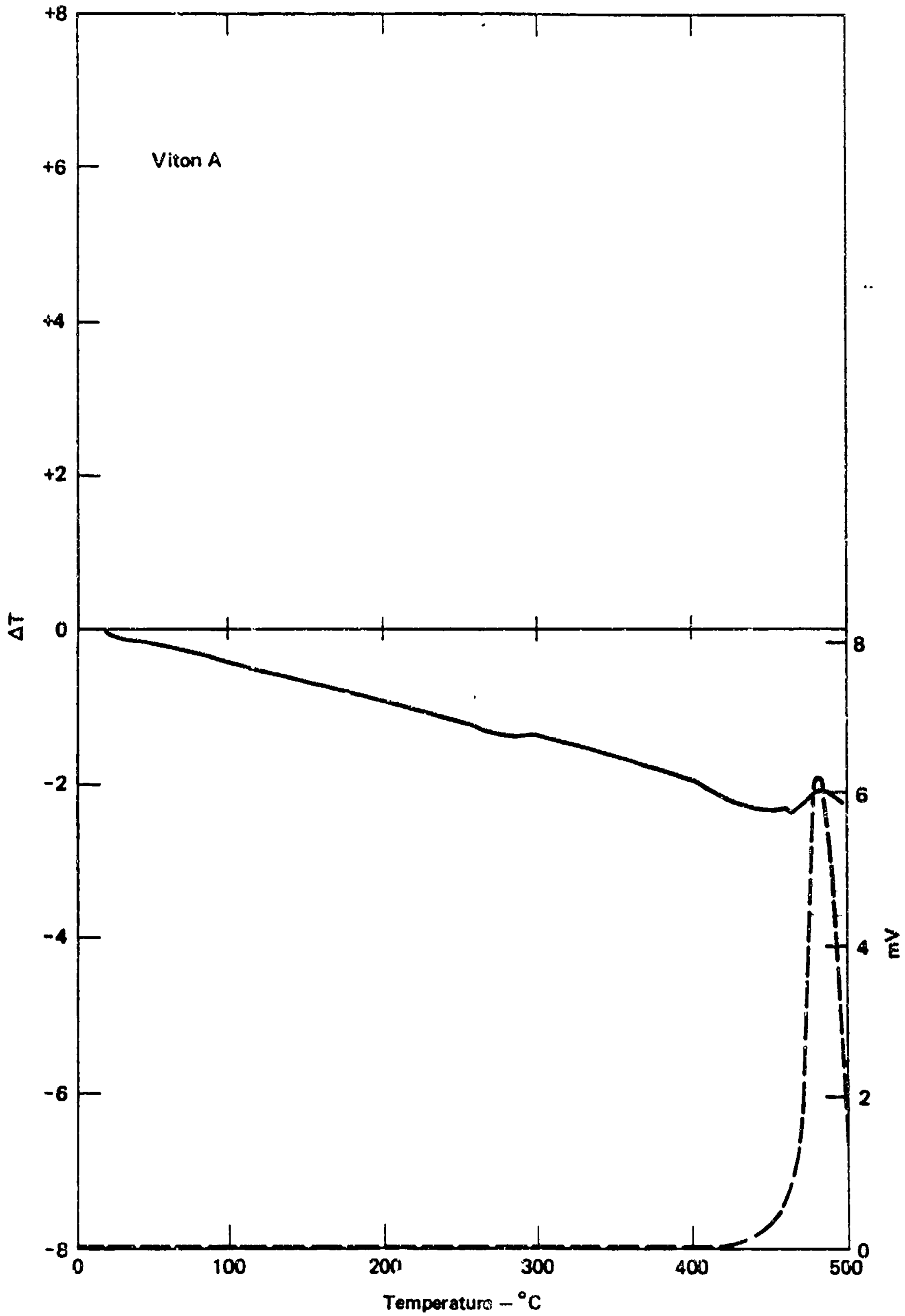


Fig. 6-6ggg. DTA curve (solid line) and pyrolysis (thermal conductivity) curve (dashed line) for Viton.[47]

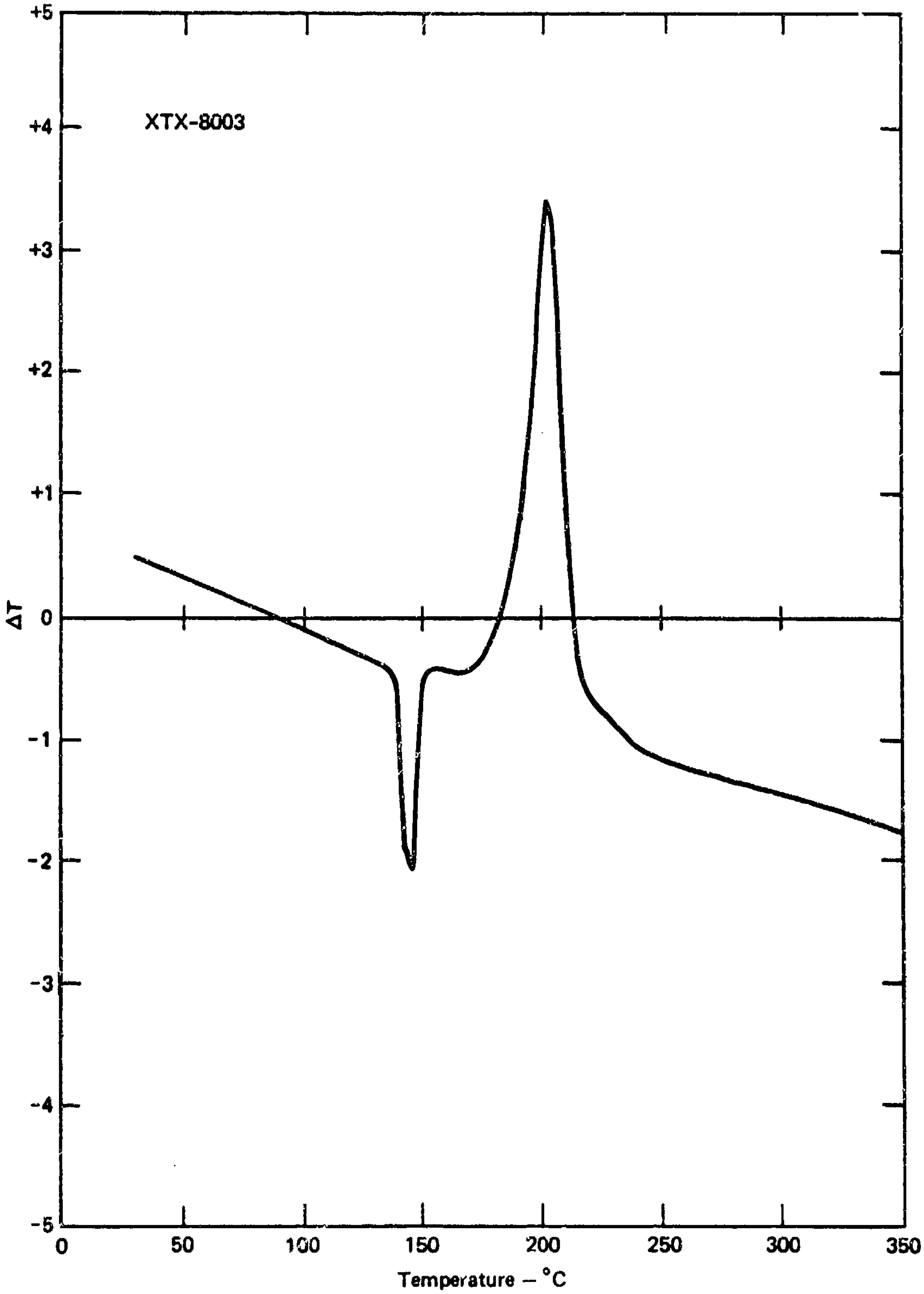


Fig. 6-6hhh. DTA curve for XTX-8003.[46]

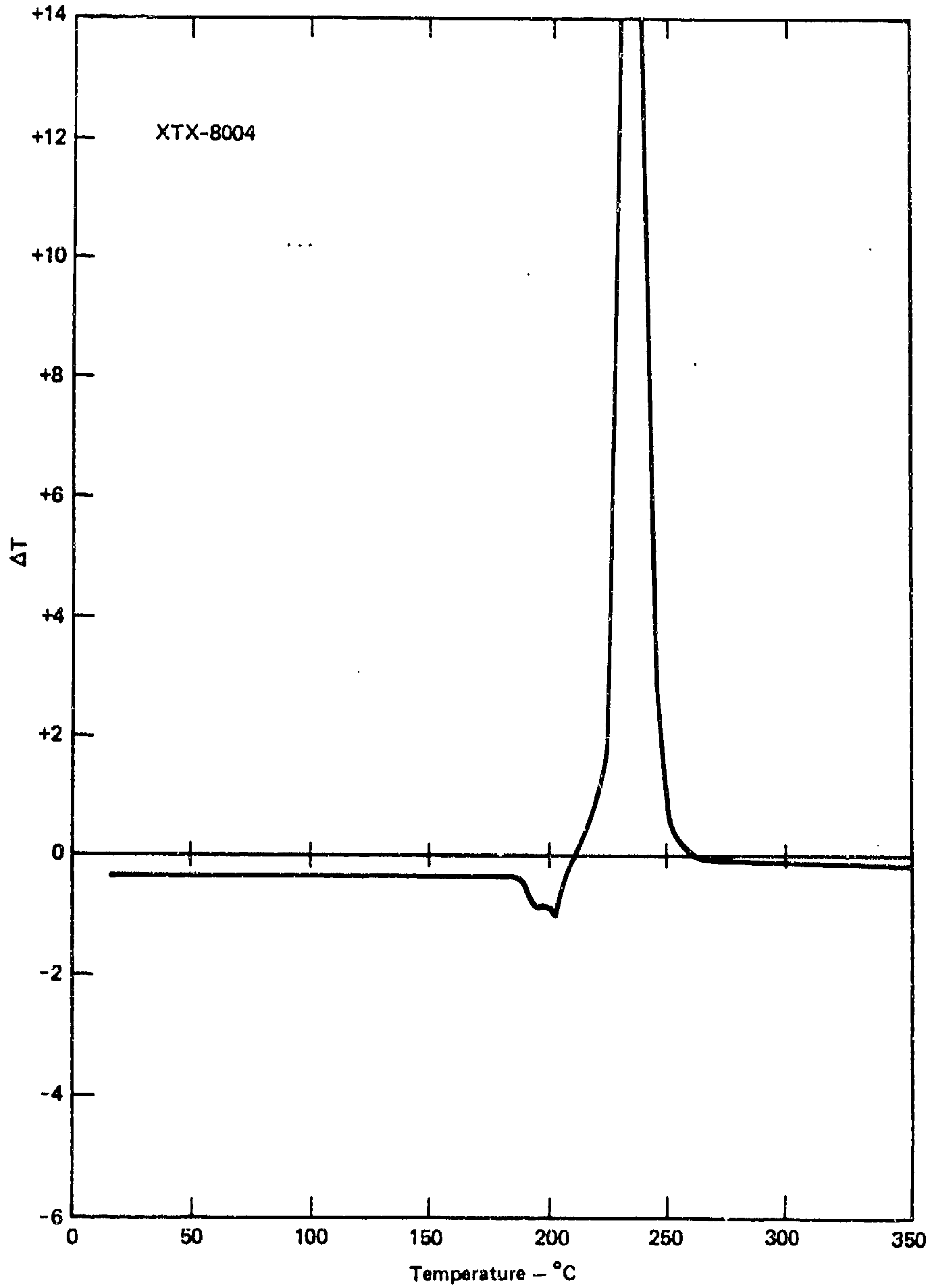


Fig. 6-6iii. DTA curve for XTX-8004.[46]

6.4.3. Thermogravimetric analysis (TGA)

The objective in a TGA is to determine whether there are any weight changes in a sample, either when it is held at a fixed temperature or when its temperature is changed in a programmed linear fashion.

The data are generally plotted as 1) weight vs temperature or time or 2) weight change vs temperature or time. The TGAs are useful for only a limited number of physical property investigations (e.g., vaporization phenomena), but they are extremely useful for obtaining information about chemical properties (e.g., thermal stability and chemical reactions). They are also used to obtain kinetic data. Sample sizes are about 10 mg. The heating rate is held at about 10°C/min in nitrogen atmosphere, and weight loss is shown as a function of temperature in Fig. 6-7.[49-51]

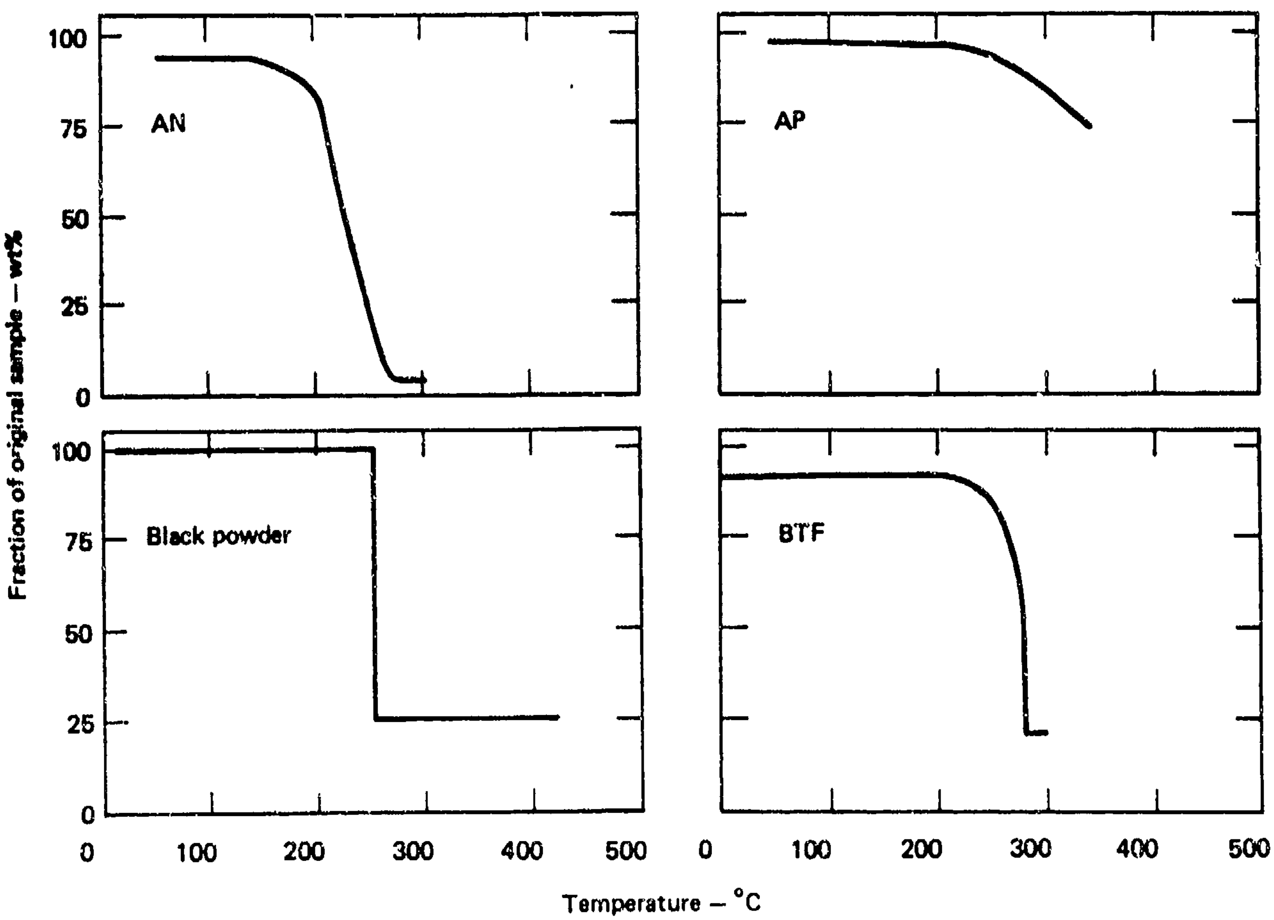


Fig. 6-7. TGA curves for explosives and binders.[49-51,57]

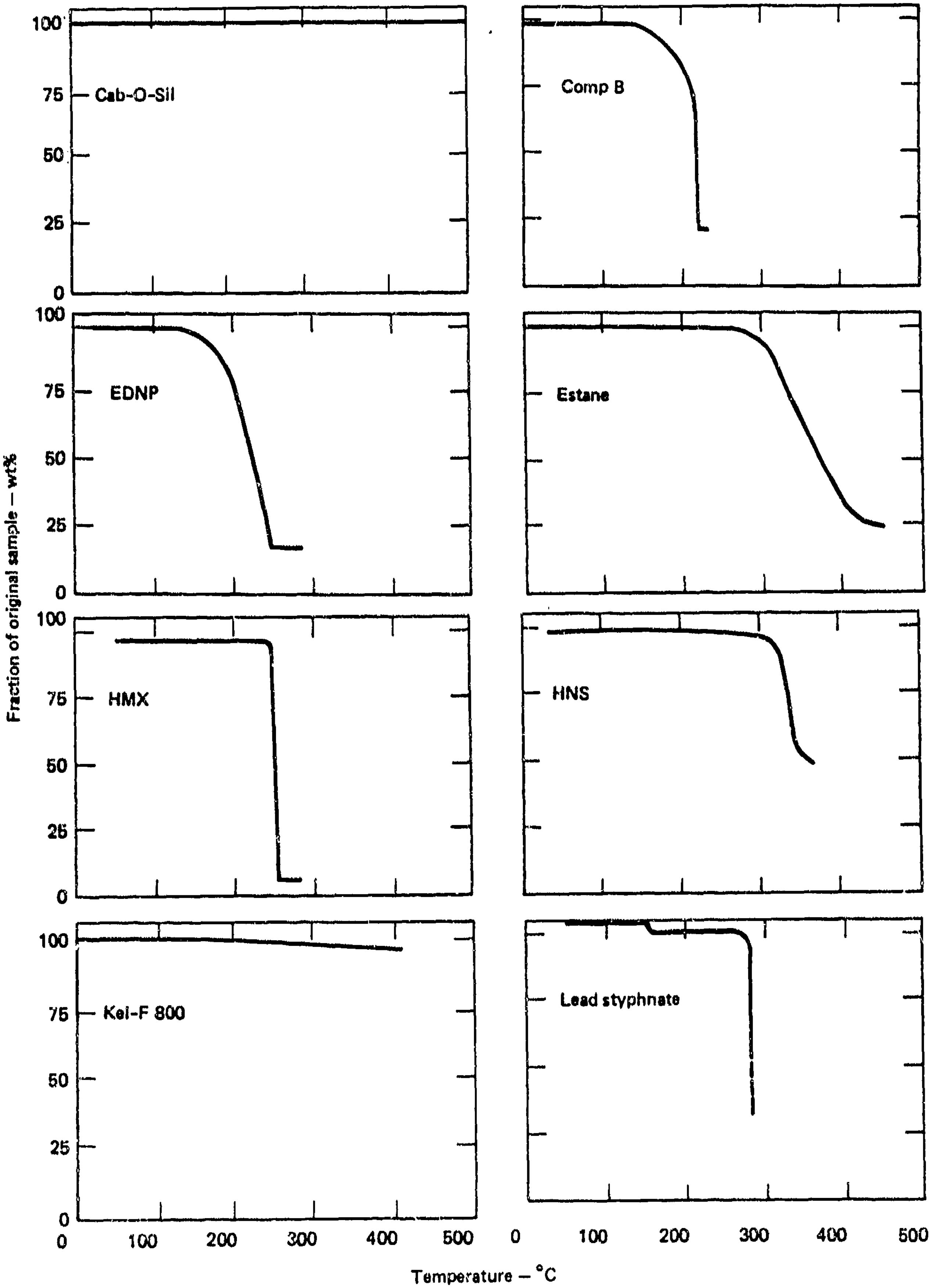


Fig. 6-7. TGA curves for explosives and binders.[49-51,57] (Continued)

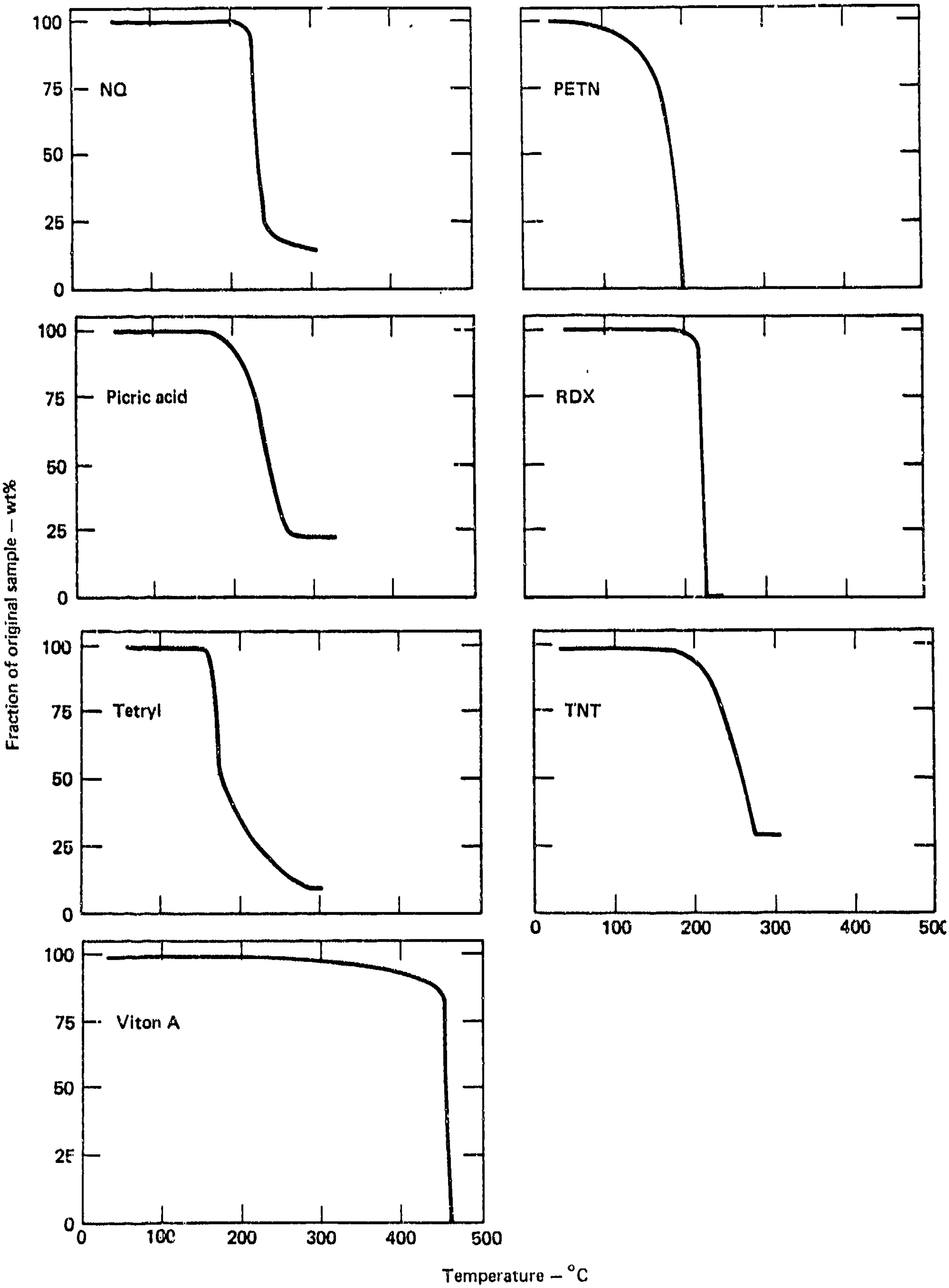


Fig. 6-7. TGA curves for explosives and binders.[49-51,57] (Continued)

6.4.4. LLNL reactivity test (CRT)

The sample is heated at 120°C (393 K) for 22 h. A two-stage chromatography unit is used to measure the individual volumes of N_2, NO, CO, N_2O, and CO_2 evolved per 0.25 g of explosive during this period. The test is operated as a simple test of explosive stability; the results are expressed in terms of the sums of these volumes. Results are given in Table 6-4.

6.4.5. Vacuum stability test

The sample is heated for 48 h at 120°C (393 K). A simple manometric system is used to measure the total volume of all gases evolved, including water and residual solvents. The results are expressed on the basis of 1 g of explosive. For reference purposes, 1 cm^3 of evolved gas/g of explosive represents about 0.2% decomposition (see Table 6-4).

Table 6-4 Thermal stabilities of various explosives.

Explosive	LLNL reactivity test[a]	Vacuum stability test[b]
Baratol	0.015-0.02	0.19
Boracitol	--	0.02-0.04
BTF	0.24-0.40	--
(purified)	0.05	--
Comp B, Grade A	0.051	0.05-0.16
Comp B-3	0.033	0.27
Comp C-4	0.026	--
Cyclotol 75/25	0.014-0.04	0.25-0.94
DATB	<0.03	<0.03
DNPA	0.04-0.06	--
EDNP	0.04-0.06	--
FEFO	0.04-0.10	--
H-6	0.096	--
HMX	<0.01	0.07
HNS	0.01	--
Lead azide	--	<0.4
Lead styphnate	--	<0.4

Table 6-4 Thermal stabilities of various explosives. (Continued)

Explosive	LLNL reactivity test[a]	Vacuum stability test[b]
LX-01	1.8[c]	--
LX-02-1	0.3-0.6	--
LX-04-1	0.01-0.04	--
LX-07-2	0.01-0.04	--
LX-09-0	0.03-0.07	--
LX-10-0	0.02	--
LX-10-1	0.04-0.06	--
LX-11	0.01-0.04	--
LX-13 (See XTX-8003)		
LX-14[10]	0.02	0.03
LX-15[52]	0.069	--
LX-16[53]	0.38	--
LX-17-0	<0.02	$\leq$0.02
Minol-2	0.105	--
NC (12.0% N)	1.0-1.2	5.0
NQ	0.02-0.05	--
Octol	0.028	0.18
PBX-9007	0.03-0.07	--
PBX-9010	0.02-0.04	0.2-0.3
PBX-9011	0.024	--
PBX-9205	0.025	--
PBX-9404	0.36-0.40	3.2-4.9
PBX-9407	0.06	--
PBX-9501	--	0.8
Pentolite 50/50	--	3.0[d]
PETN	0.10-0.14	--
RDX	0.02-0.025	0.12-0.9
Tetryl	0.036	--
TNT	0.00-0.012	~0.005
XTX-8003	<0.02[d]	--
XTX-8004	~0.06	--

[a] Volume of gas (cm^3 at STP)/0.25 g evolved in 22 hr at 120°C (393) K.
[b] Volume of gas (cm^3 at STP)/g evolved in 48 hr at 120°C (393) K.
[c] Measured at 80°C (353 K) because of the high volatility of the material.
[d] Measured at 100°C (373 K).

6.4.6. Critical temperature and time to explosion

For safety reasons it is desirable to be able to predict the response of an explosive to high temperatures, i.e., to determine a "time to explosion" (t) and a "critical temperature" (T_c) experimentally or by calculation. T_c is defined as the lowest temperature at which an HE of a given configuration self-heats to explosion. Such times and (to a lesser extent) temperatures vary with the size, shape, previous history, and initial conditions of the sample; they must therefore be determined for each sample and situation.

Using the Frank-Kamenetskii equation, critical temperatures and times to explosion can be predicted by

$$-\lambda \nabla^2 T + \rho C(\partial T/\partial t) = \rho \Delta H \; Z \; e^{-E/RT}$$

and its asymptotic solution at infinite time,

$$E/T_c = R \ln \frac{a^2 \rho Q Z E}{T_c^2 \lambda \delta R} ,$$

where

- E = activation energy in cal/mol,
- C = heat capacity in cal/g-deg,
- T_c = critical temperature for a specific geometry in K,
- t = time to explosion for a specific geometry in s,
- R = gas constant, 1.9872 cal/K-mol,
- a = radius of a sphere, cylinder, or half thickness of a slab in cm,
- ρ = density in g/cm^3,
- Q = heat of reaction in cal/g,
- ΔH = heat of decomposition in cal/g,
- Z = pre-exponential factor in s^{-1},
- ∇^2 = LaPlace operator,
- λ = thermal conductivity in cal/cm-sec-°C,
- δ = shape factor: 0.88 for an infinite slab, 2.00 for an infinite cylinder, and 3.32 for a sphere.

The calculational results are listed with their corresponding parameters and with experimental critical explosion temperatures in Table 6-5. Times to

explosion for several HEs are plotted vs inverse temperature in Fig. 6-8.[58] The effect of sphere diameter on critical temperature is shown in Fig. 6-9.[59]

LANL uses a modified Henkin test in which a 40-mg sample of measured thickness is confined in a blasting cap and heated to explosion in a preheated Woods metal bath. The seal, formed by flaring an aluminum cap inside the blasting cap, allows the product gases to escape under pressure.

Results from Henkin tests for times to explosion have been intentionally excluded from this compilation. Although the data available for small, well-defined samples are reliable, they cannot be applied to large samples or charges whose thermal history and characterization are unknown.

Activation energies are determined at Los Alamos from DSC measurements, and are given in Table 6-5.

In the LLNL "One-Dimensional Time to Explosion" (ODTX) Test, 2.2-g samples (12.7-mm-diam sphere) are placed between two preheated anvil faces (76.2-mm diam x 50.8-mm high) and sealed to confine the detonation product gases. The anvils are heated electrically; the temperature is controlled by thermocouple feedback. Times to explosion are measured as a function of temperature (Fig. 6-8). Critical temperatures are defined as the asymptote of the ln t vs 1/T plot. The ODTX data have been extrapolated to quite large samples using finite-element thermal codes with subroutines for chemical decomposition (TACO). This analysis can be extended to other HMX-containing plastic-bonded explosives if the thermal boundary conditions are well-defined. Parameters for the Arrhenius equations for ODTX experiments are excluded from Table 6-5 because these data are interpreted by techniques different from the LANL data.

6.4.7. Thermal stability of larger explosive charges

For large amounts of explosive, the results from small-scale thermal stability tests are not strictly applicable. The maximum safe temperature, not to be exceeded, is the point at which thermal energy from slow chemical decomposition is given off faster than it can be dissipated. It is called the self-heating temperature and is dependent on the amount of explosive, its environment, and the time it is held at the elevated temperature (see Section 6.4.6.). For example, 1) 25 lb (11.34 kg) of LX-04-1 may be held at 190°C (463 K) for no more than 10 min. 2) Calculations indicate that about 13,000 lb (about 6 tons) of molten TNT may be unsafe.

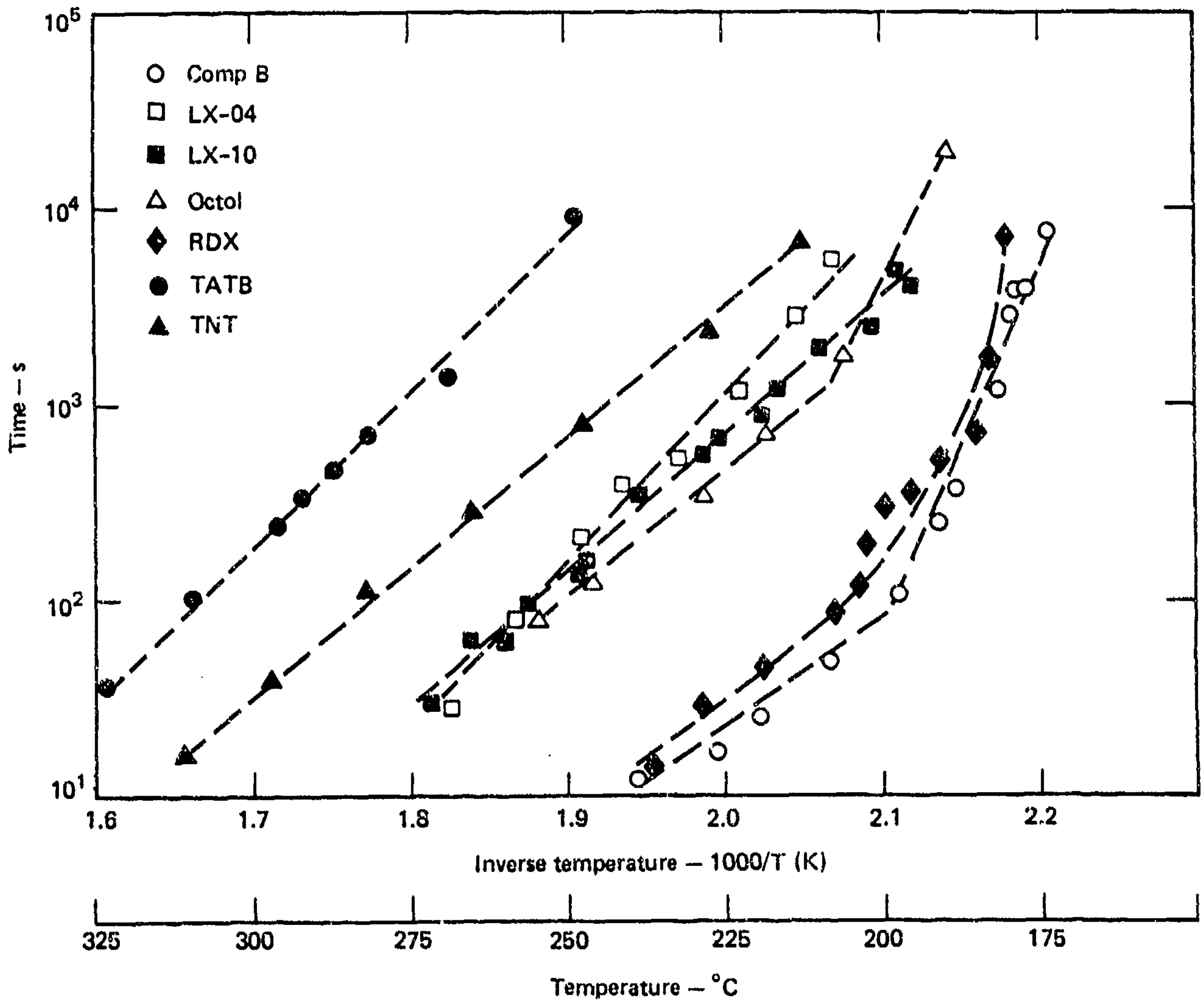


Fig. 6-8. Times to explosion for HEs vs inverse temperature from ODTX tests.[58]

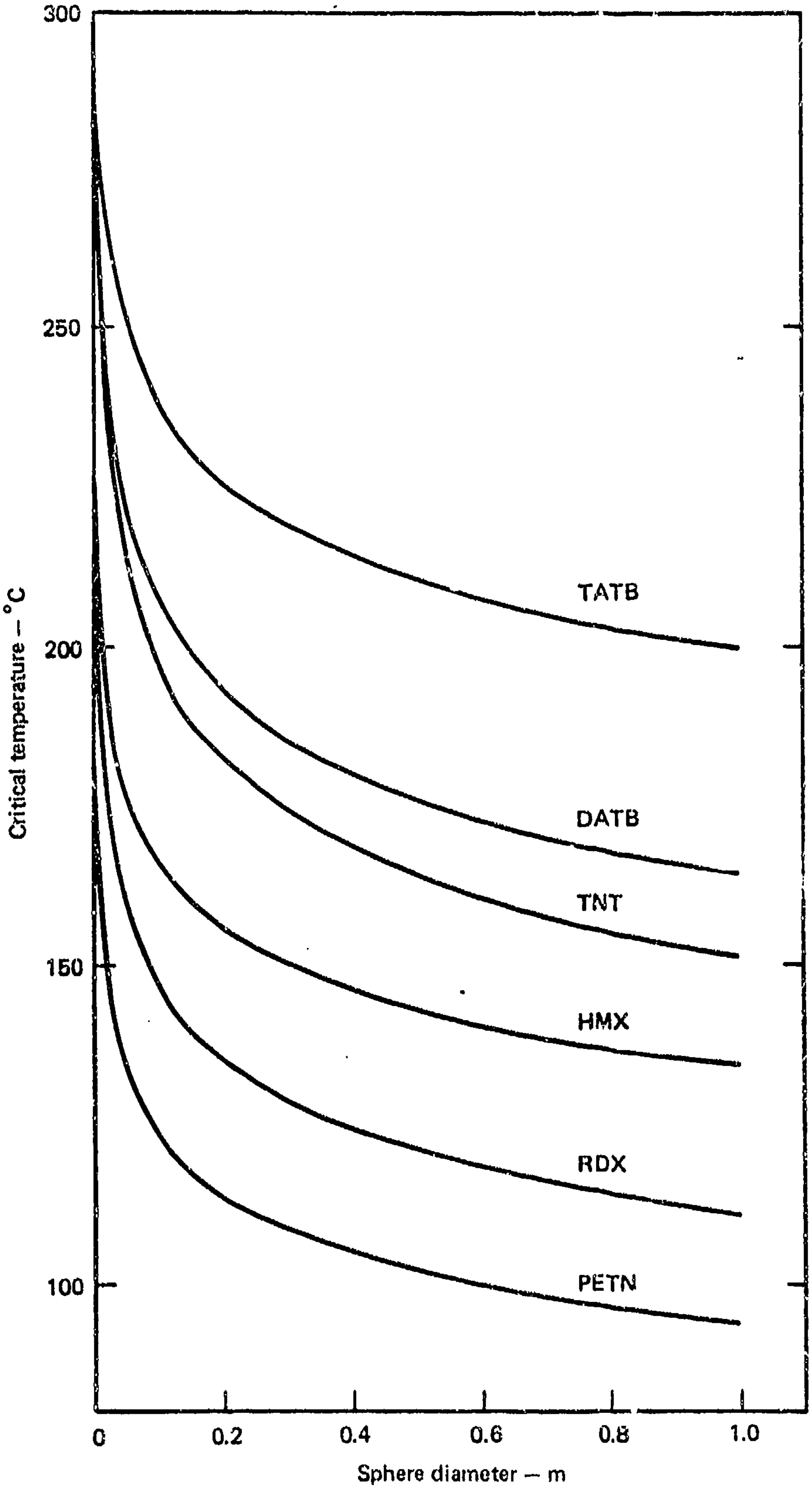


Fig. 6-9. Critical temperatures vs charge diameter for some pure explosives.[59]

Table 6-5. Critical explosion temperatures.

HE	Sample thickness, d (mm)	T_c (°C) Exp.[a]	T_c (°C) Calc.	Parameters: a (cm)	ρ g/cm^3 (Mg/m^3)	Q cal/g (kJ/kg)	Z s^{-1}	E kcal/mol (kJ/mol)	λ 10^{-4} cal/cm-sec-°C (W/m-K)	Ref.
BTF	0.66	248-251	275	0.033	1.81	600 (2510)	4.11×10^{12}	37.2 (155.7)	5.0 (0.209)	60
Comp B	0.80	216	215	0.040	1.58	758 (3171)	4.62×10^{16}	43.1 (180.3)	4.7 (0.197)	59
DATB	0.70	320-323	323	0.035	1.74	300 (1255)	1.17×10^{15}	46.3 (193.8)	6.0 (0.251)	60
HMX	0.3	258	253	0.033	1.81	500 (2092)	5×10^{19}	52.7 (220.5)	7.0 (0.293)	59,60
HNS	0.74	320-321	316	0.037	1.65	500 (2092)	1.53×10^{9}	30.3 (126.8)	5.0 (0.209)	60
LX-10	0.284	191								61
NQ	0.78	200-204	204	0.039	1.63	500 (2092)	2.84×10^{7}	20.9 (87.5)	5.0 (0.209)	60
PETN	0.8	197	196	0.034	1.74	300 (1255)	6.3×10^{19}	47.0 (196.7)	6.0 (0.251)	60
	0.762	197								61
RDX (Holston)	0.8	214	217	0.035	1.72	500 (2092)	2.02×10^{18}	47.1 (197.1)	2.5 (0.106)	59,60
TATB	0.7	353	334	0.033	1.84	600 (2510)	3.18×10^{19}	59.9 (250.6)	10.0 (0.418)	60
	0.77	353								59
	0.284	246								61
	0.635	230								61
TNT	0.80	286	291	0.038	1.57	300 (1255)	2.51×10^{11}	34.4 (143.9)	5.0 (0.209)	59,60
	0.284	235								61
	0.635	205								61

[a] All experimental critical temperatures (T_c) are for the stated sample thickness d.

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7. MECHANICAL PROPERTIES

This chapter includes data on time- and rate-dependent as well as complex modulus responses, on static and kinematic friction, on sound velocities, and on Hugoniot parameters.

High explosives are viscoelastic materials. Their mechanical properties are functions of time, temperature, and loading rate. These properties vary in any one material because of differences in raw material from one lot to another, differences in pressing conditions, and differences in the machining procedures used to fabricate the materials. Therefore, the data in this section are not intended to provide exact numerical values but rather to demonstrate general trends and to compare different materials. In order to make more refined calculations for predicting the behavior of systems, each individual lot of HE must be characterized.

To characterize materials over the entire temperature range from -65 to 165°F (219-347 K), certain assumptions must be made:

1. The material is homogeneous and isotropic.
2. Explosives can be characterized on the basis of their elastic and viscoelastic behavior.
3. The "failure envelope" provides a usable criterion of failure.

These assumptions have been explored experimentally and found to be reasonable.

When HE assemblies are joined with adhesives, the compliance of the adhesive must be considered. Most adhesives used with HEs are stronger but more compliant than the explosive. The bond is usually stronger than the HE when clean surfaces and recommended assembly procedures are used. If the assembly will be subjected to stress analysis, the adhesive bond can be modeled as a viscoelastic material. Other conditions to be considered are aging of the materials and crystallinity of the binder.

A series of codes for nonlinear two- and three-dimensional analyses has been developed to predict static and dynamic thermal and mechanical behavior of HEs and binders under various conditions. Behavior that can be modeled with these codes ranges from simple uniaxial stress-strain to complex stress states.[1,2]

7.1. TIME- AND RATE-DEPENDENT MECHANICAL PROPERTIES

In this section, experimental data are given for characterization of mechanical properties at constant strain rates in tension and compression: tensile stress-strain data, failure envelopes, initial uniaxial modulus (E_0), and tensile creep.[3-5,43] The stress-strain data were generated at constant strain rates and constant crosshead velocities.

A failure envelope is generated for a material from the stress-at-break values obtained in tensile tests at different temperatures and constant strain rate (i.e., isothermal, monotonically increasing tension loads).

7.1.1. Tensile tests

Tensile stress-strain. Figure 7-1 shows tensile stress-strain curves for several PBXs at different temperatures. Construction of failure envelopes is also indicated for two of the materials.

Failure envelope. Figure 7-2 shows failure envelopes for several PBXs stressed at a constant strain rate.

Initial uniaxial modulus. Initial uniaxial moduli are derived from tensile and compression data; they are temperature dependent because the properties of the polymeric binders are temperature dependent. Time- and rate-dependence also shows that plastic-bonded explosives are viscoelastic materials. Figure 7-3 shows the initial uniaxial moduli of HEs as a function of temperature.

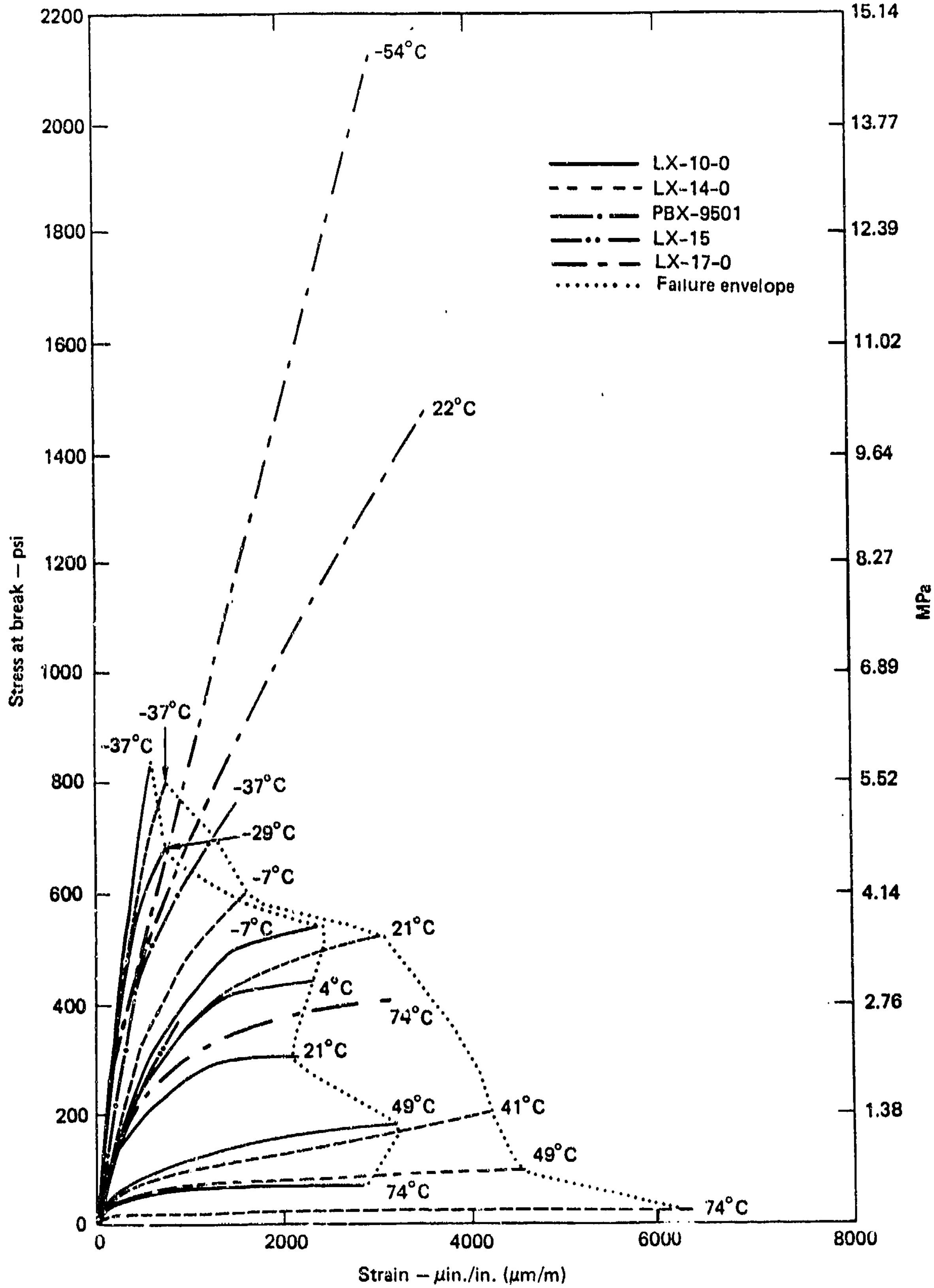


Fig. 7-1. Tensile stress-strain curves for several PBXs at different temperatures. Crosshead velocity was 0.002 mm/s and strain rate was $1.25 \times 10^{-5}\ s^{-1}$.

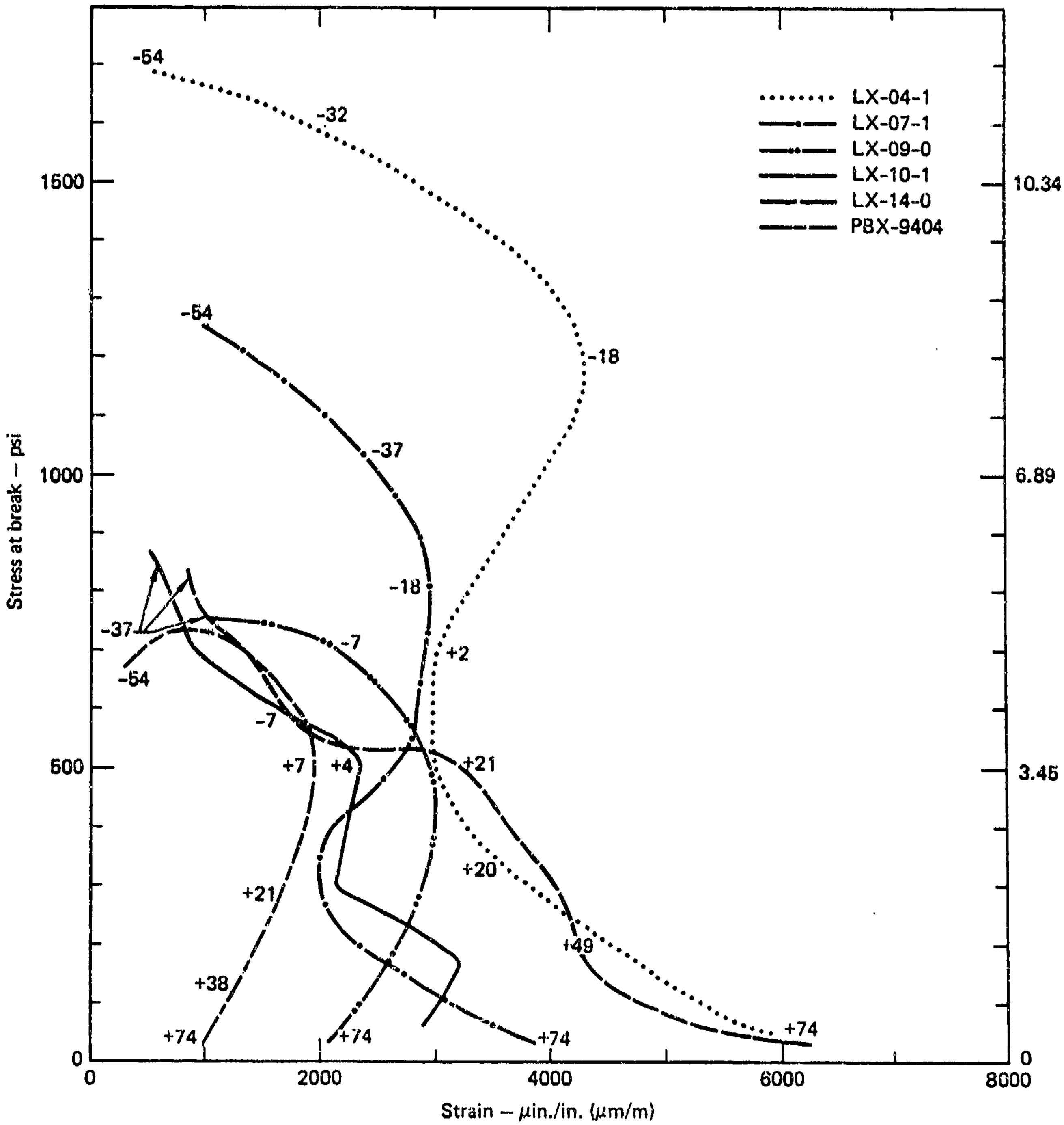


Fig. 7-2. Failure envelopes for several PBXs stressed at a constant strain rate (1.25×10^{-5} s^{-1}). Conversion factor: 1 psi = 6.895 kPa. The numbers on the curves are temperatures in °C.

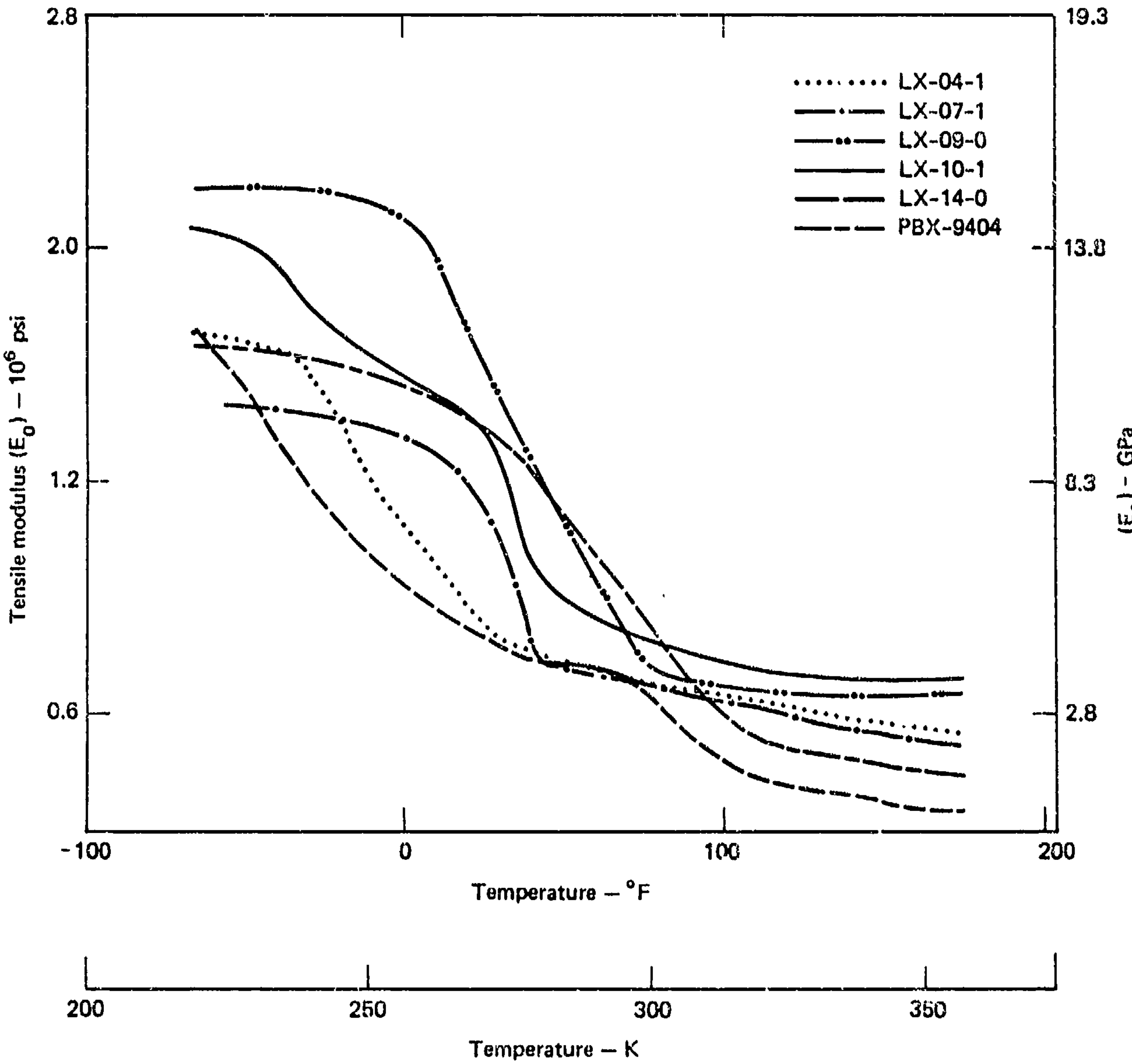


Fig. 7-3. Initial uniaxial moduli of HEs as a function of temperature. Conversion factor: 1 psi = 6.895 kPa.

Tensile creep. The creep compliance J(t) is defined by:

$$J(t) = \epsilon(t)/\sigma \ ,$$

where J is creep compliance, t is time, ϵ is strain, and σ is a step function in stress. Tensile creep data for PBX-9501 are shown in Fig. 7-4. Figure 7-5 shows tensile creep compliance for several explosives.

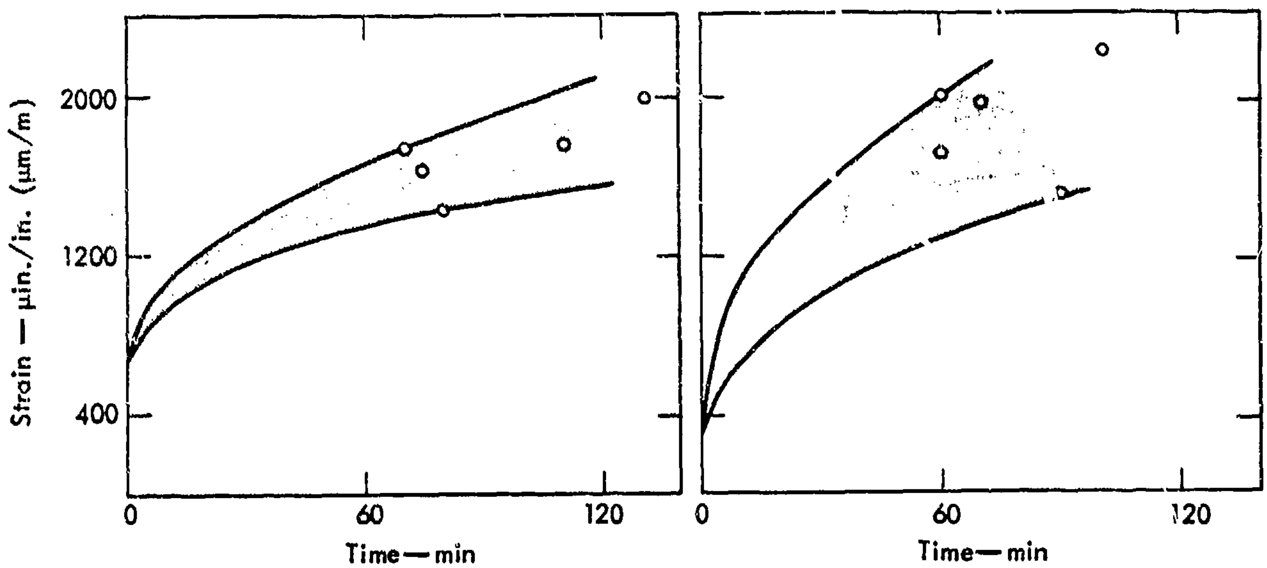


Fig. 7-4. Tensile creep data for PBX-9501 (a) at 100 psi (689 kPa) and 70°F (294 K) and (b) at 50 psi (345 kPa) and 120°F (322 K). The shaded area indicates the range; the points indicate rupture of the specimen.

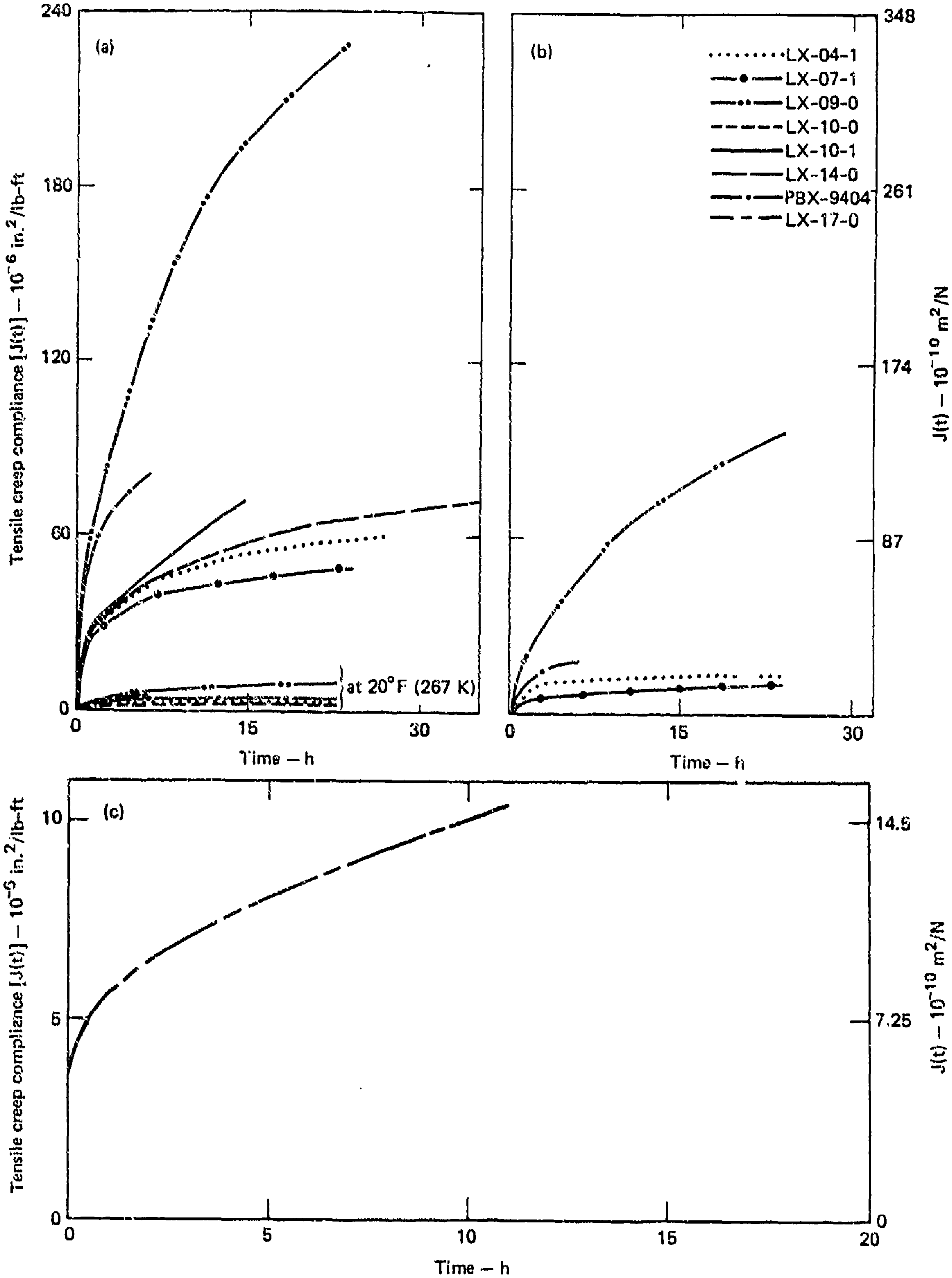


Fig. 7-5. Tensile creep compliance (J(t)) for several explosives. Conversion factor: 1 in.^{2}/lb-ft. = 1.45 x 10^{-4} m^2/N. (a) Creep compliance at 50 psi (0.345 MPa) and 120°F (322 K) and 20°F (267 K). (b) Creep compliance at 50 psi (0.345 MPa) and 70°F (294 K). (c) Creep compliance at 250 psi (1.7 MPa) and 165°F (347 K).

High-strain-rate tensile tests. Mechanical and fracture properties at high strain rates can be obtained using the Hopkinson split-bar.[6-8,43] The type of fracture can be identified by examining the fracture surfaces and the stress-strain curves. Table 7-1 lists ultimate tensile strengths and the type of fractures observed when specimens were stressed at increasing strain rates. Figure 7-6 shows the tensile modulus as a function of strain rate; the tensile moduli for LX-04-1 and LX-07-1 obtained from high-frequency ultrasonic measurements are shown for comparison.

Table 7-1. Static tensile strength.[7]

Material	Strain rate (s^{-1})	Ultimate stress psi	Ultimate stress (MPa)	Type of fracture
LX-04-1	10^{-4}	340	(2.34)	Slightly ductile
	850	1500	(10.34)	Slightly ductile
	1100	1780	(12.27)	Slightly ductile
	1550	1750	(12.07)	Brittle
	3100	2100	(14.48)	Slightly ductile
LX-14-0	10^{-5}	450	(3.1)	Brittle
	10^{-4}	540	(3.7)	Brittle
	10^{-3}	580	(4.0)	Brittle
PBX-9011	10^{-4}	340	(2.34)	Slightly ductile
	1050	1300	(8.96)	Brittle
	1100	1450	(10.00)	Brittle
	1300	1400	(9.65)	Brittle
PBX-9404	10^{-4}	330	(2.28)	Slightly ductile
	950	1200	(8.27)	Brittle
	1070	1500	(10.34)	Slightly ductile
	1100	1340	(9.24)	Brittle
	1850	1510	(10.41)	Brittle
PETN	10^{-3}	160	(1.10)	Brittle
	10^{-2}	215	(1.48)	Brittle
	10^{-1}	215	(1.48)	Brittle
	1000	720	(4.96)	Brittle
	1120	700	(4.83)	Brittle
	1300	785	(5.41)	Brittle
	2600	840	(5.79)	Brittle

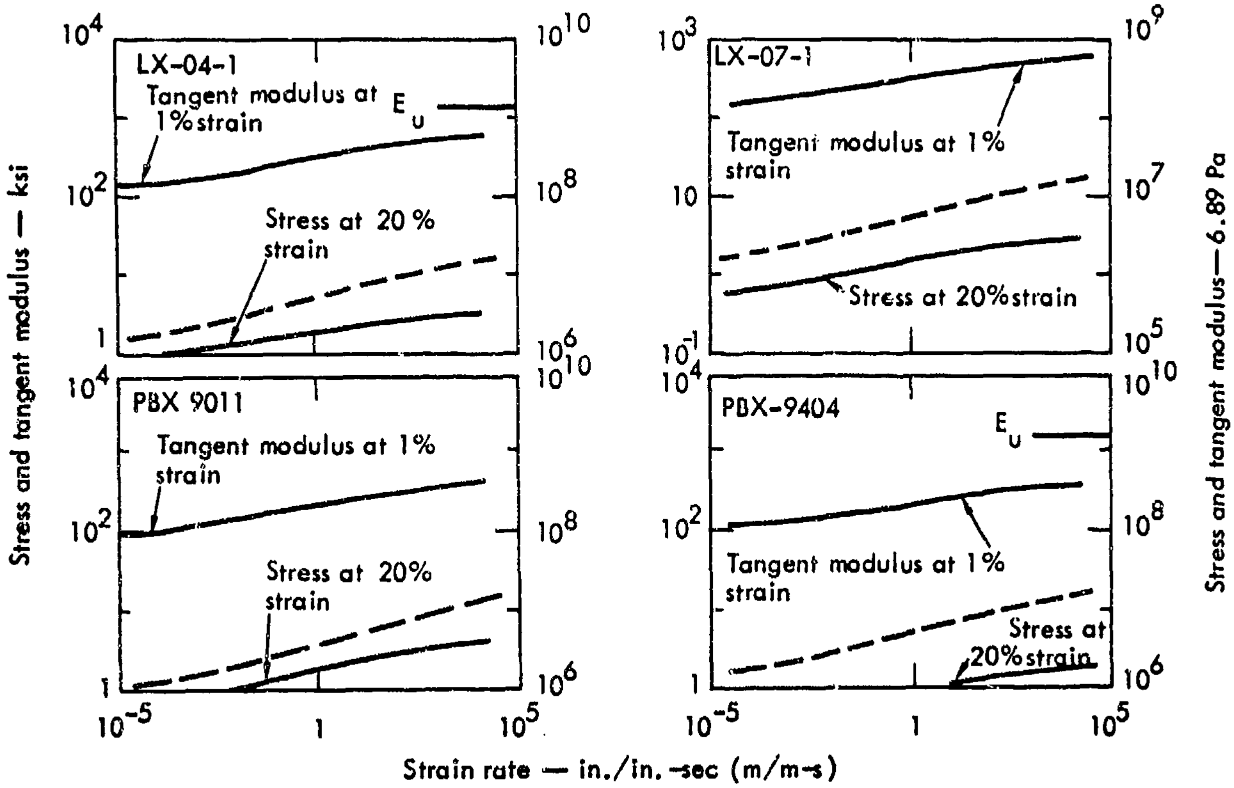


Fig. 7-6. Tensile stress and tangent moduli of several explosives as a function of strain rate; the dashed line represents ultimate stress. The curves for LX-04-1 and LX-07-1 show the ultrasonically determined modulus E_u and are shown for comparison. Conversion factor: 1 psi = 6.895 kPa.

7.1.2. Compressive tests

Compressive stress-strain. Figure 7-7 shows the strain rate dependence of stress-strain curves for a variety of PBXs. Some of these measurements were made using the Hopkinson split bar in uniaxial compression.

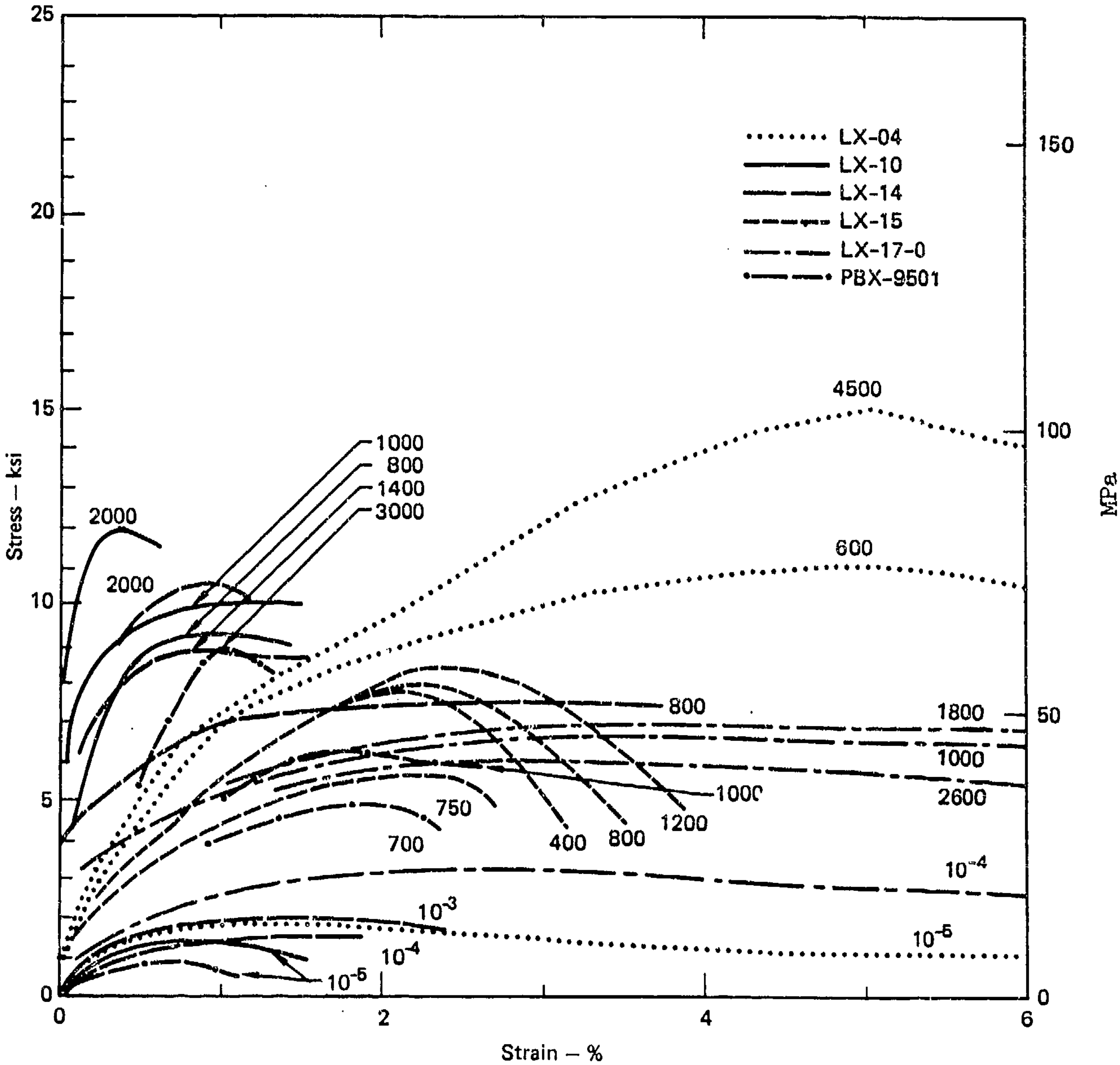


Fig. 7-7. Uniaxial compression data at ambient temperature for several HEs at different strain rates. Numbers on the curve are strain rates in s^{-1}. Conversion factor: 1 psi = 6.895 kPa.

<u>Compressive creep</u>. Figure 7-8 shows compressive creep data for LX-14, LX-17, and PBX-9501.

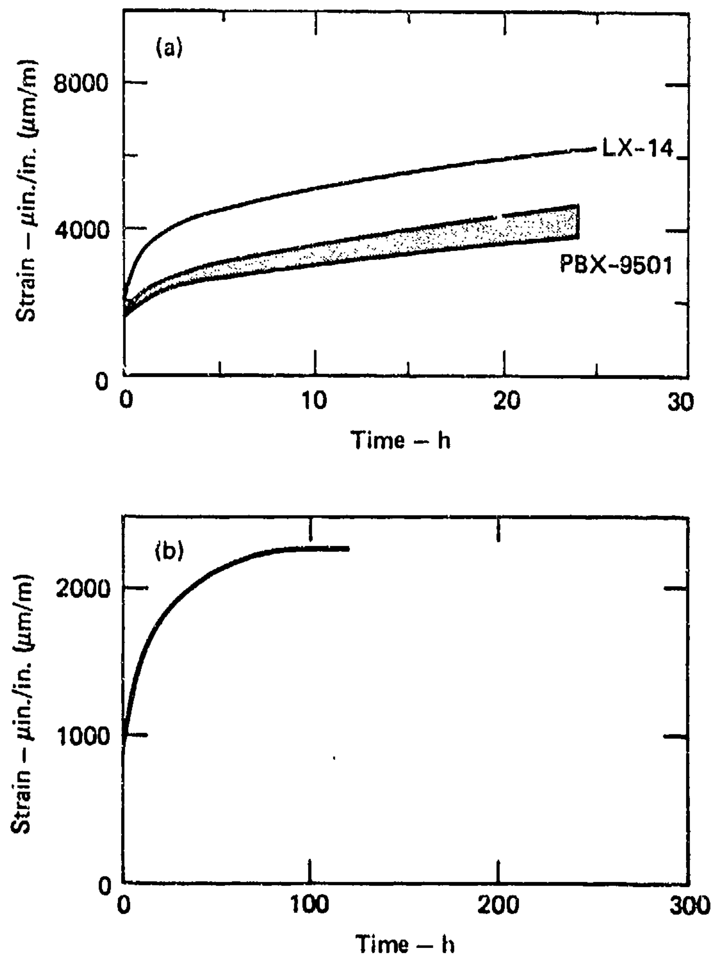


Fig. 7-8. Compressive creep data for (a) LX-14 and PBX-9501 at 100 psi (0.689 MPa), 120°F (322 K) and (b) LX-17-0 at 250 psi (1.7 MPa) and 74°C (347 K). The shaded region indicates the range of values observed.

7.2. COMPLEX MODULUS PROPERTIES

7.2.1. Complex shear

The complex shear modulus (G*) has been determined by measuring its components: the shear storage modulus (G') and the shear loss modulus (G"). Plastic-bonded high explosives are treated here as homogeneous, isotropic, linear viscoelastic and thermo-rheologically simple materials. Measurements were made using a Rheometric Mechanical Spectrometer (RMS).

The appropriate relationships are:

$$G^* = G' + i\,G'' ,$$

where $i = \sqrt{-1}$, and

$$G''/G' = \tan\delta ,$$

where $\tan\delta$ (a damping term) also expresses the ratio of energy dissipated as heat to the maximum energy stored in the sample during one oscillatory cycle. Figures 7-9 and 7-10 show G', G", and $\tan\delta$ for various HEs and binders measured with the RMS at 1 Hz.[9,43] Figure 7-11 shows the observed shear storage and shear loss moduli of LX-04 reduced to a temperature T_r of 22°C (295 K) by the WLF empirical equation[12] over the frequency range from 10^{-5} to 1 GHz.

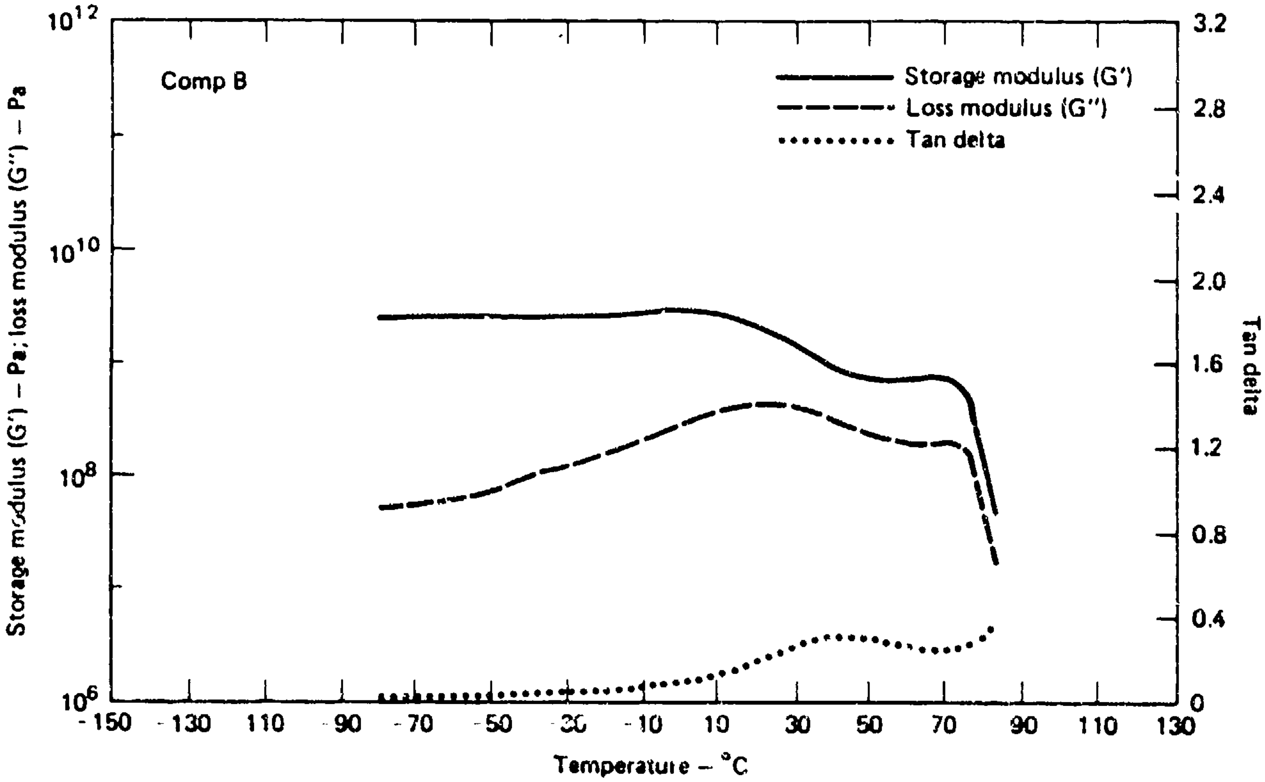


Fig. 7-9a. Values of G', G'', and tan δ for Comp B measured with the RMS at 1 Hz.[9]

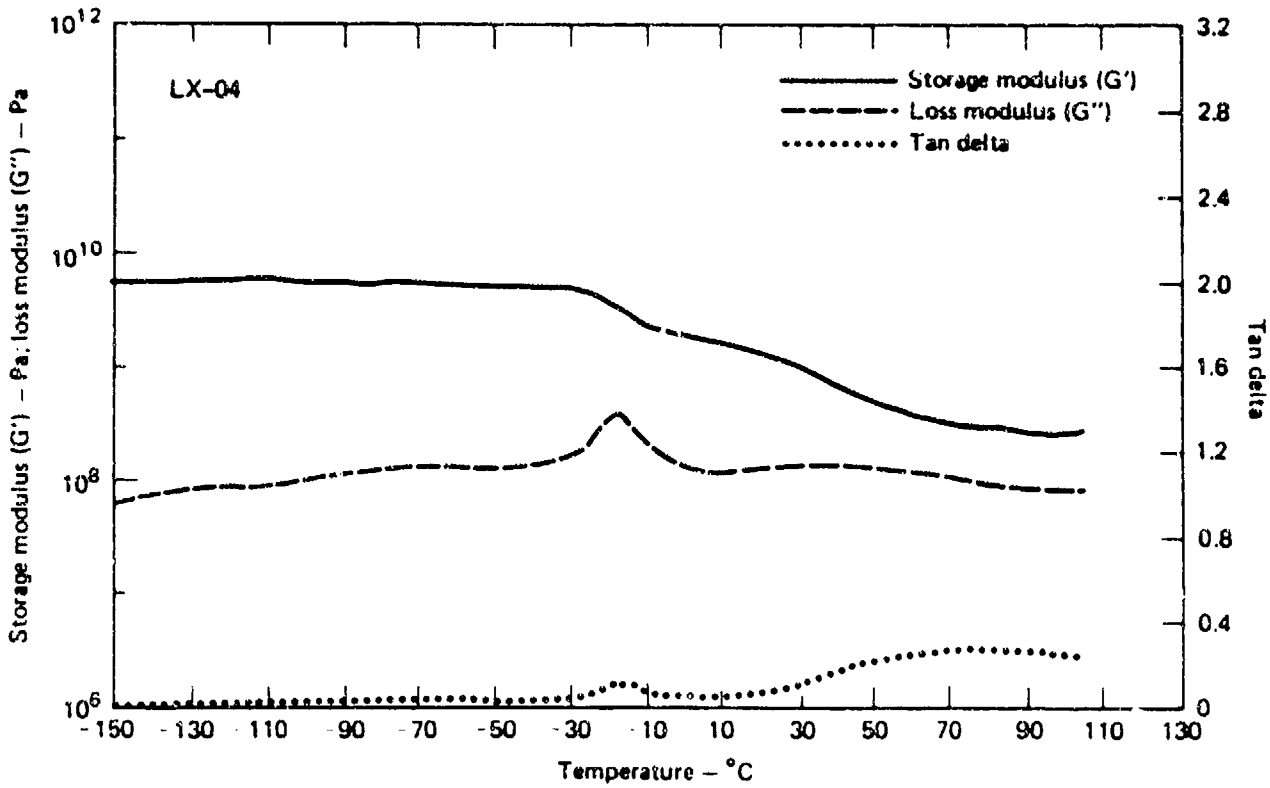


Fig. 7-9b. Values of G', G'', and tan δ for LX-04 measured with the RMS at 1 Hz.[9]

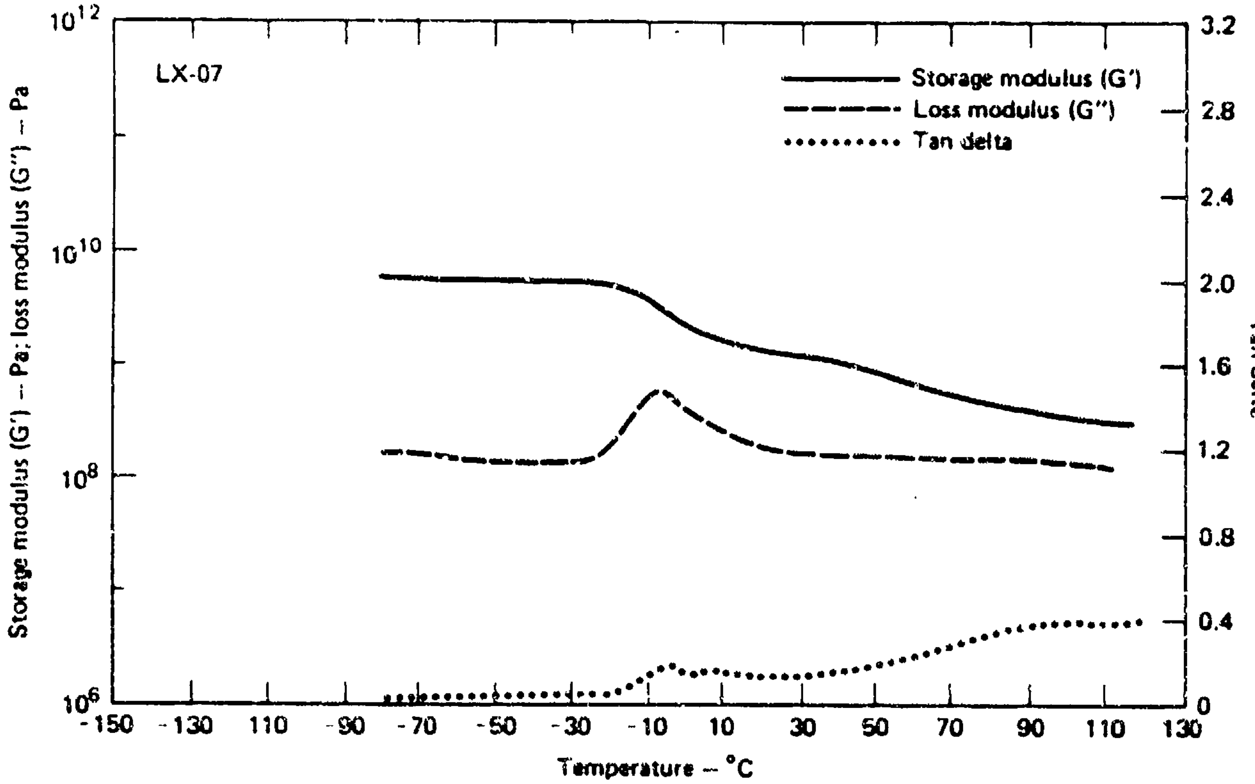


Fig. 7-9c. Values of G', G'', and tan δ for LX-07 measured with the RMS at 1 Hz.[9]

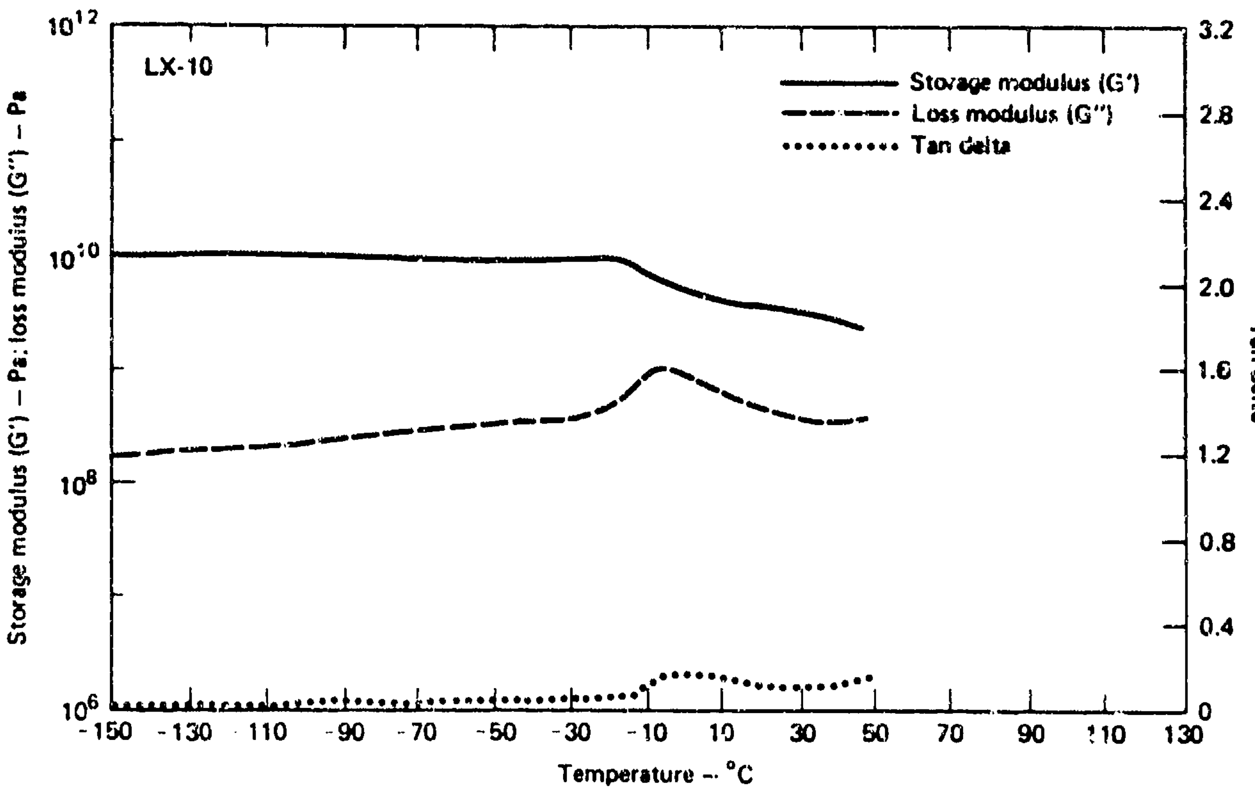


Fig. 7-9d. Values of G', G'', and tan δ for LX-10 measured with the RMS at 1 Hz.[9]

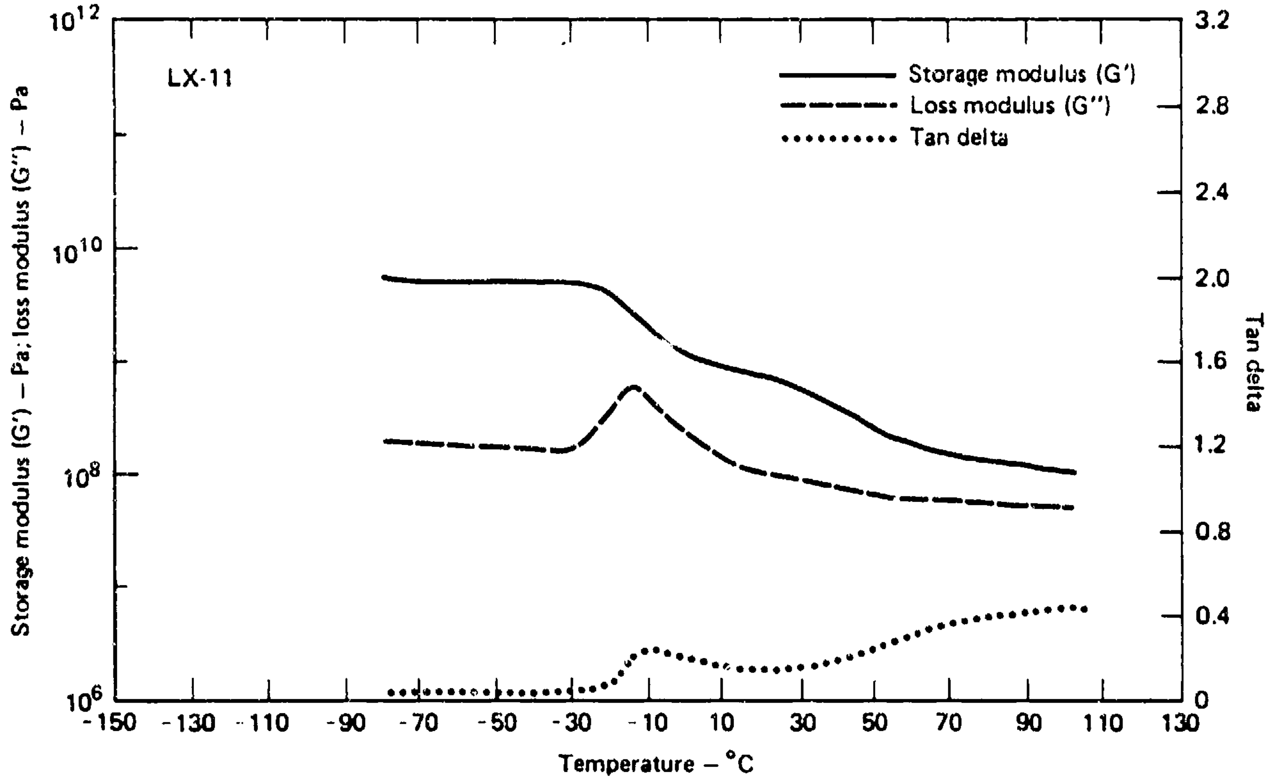


Fig. 7-9e. Values of G', G'', and tan δ for LX-11 measured with the RMS at 1 Hz.[9]

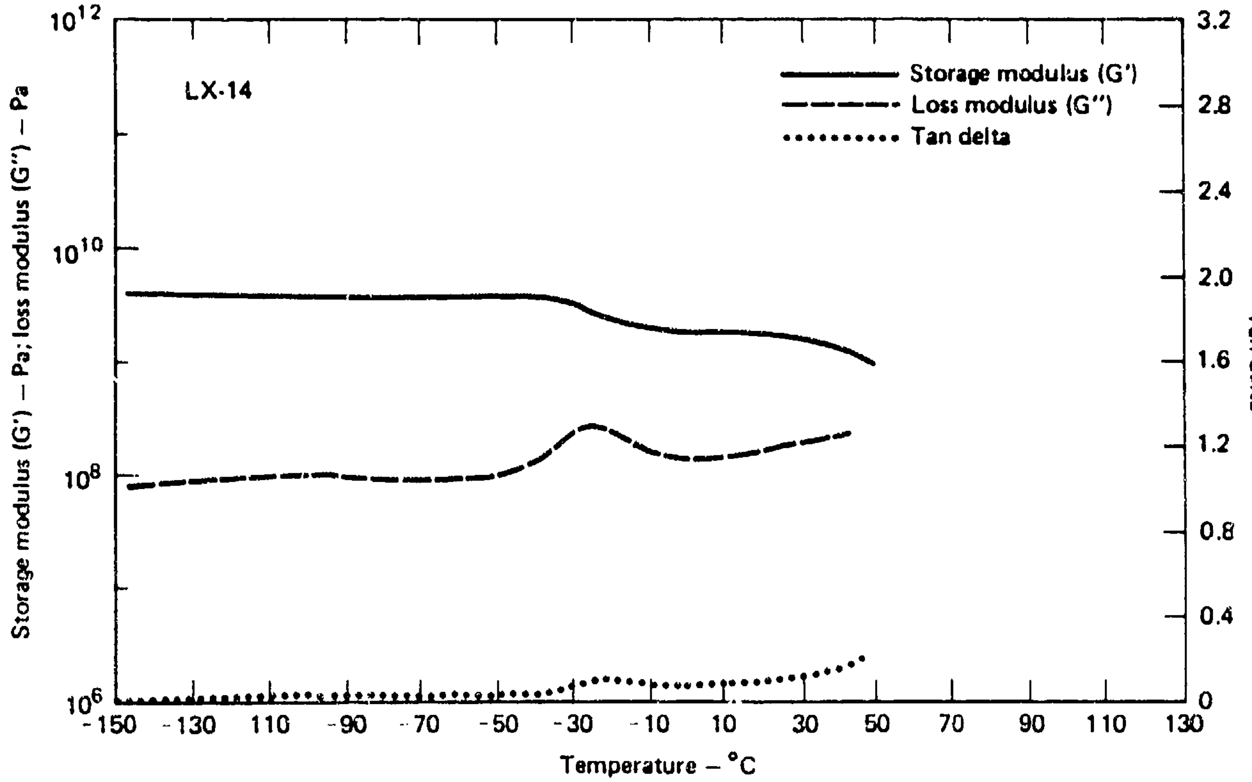


Fig. 7-9f. Values of G', G'', and tan δ for LX-14 measured with the RMS at 1 Hz.[9]

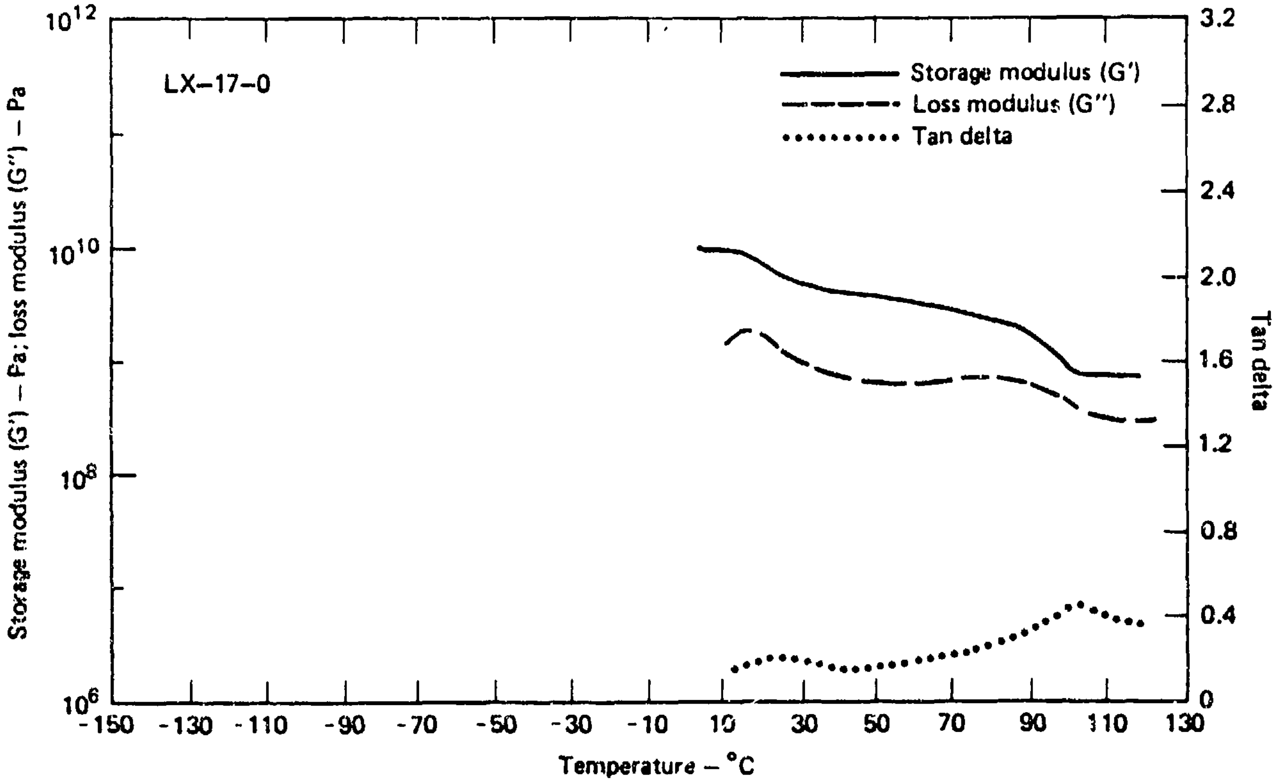


Fig. 7-9g. Values of G', G'', and tan δ for LX-17 measured with the RMS at 1 Hz.[9]

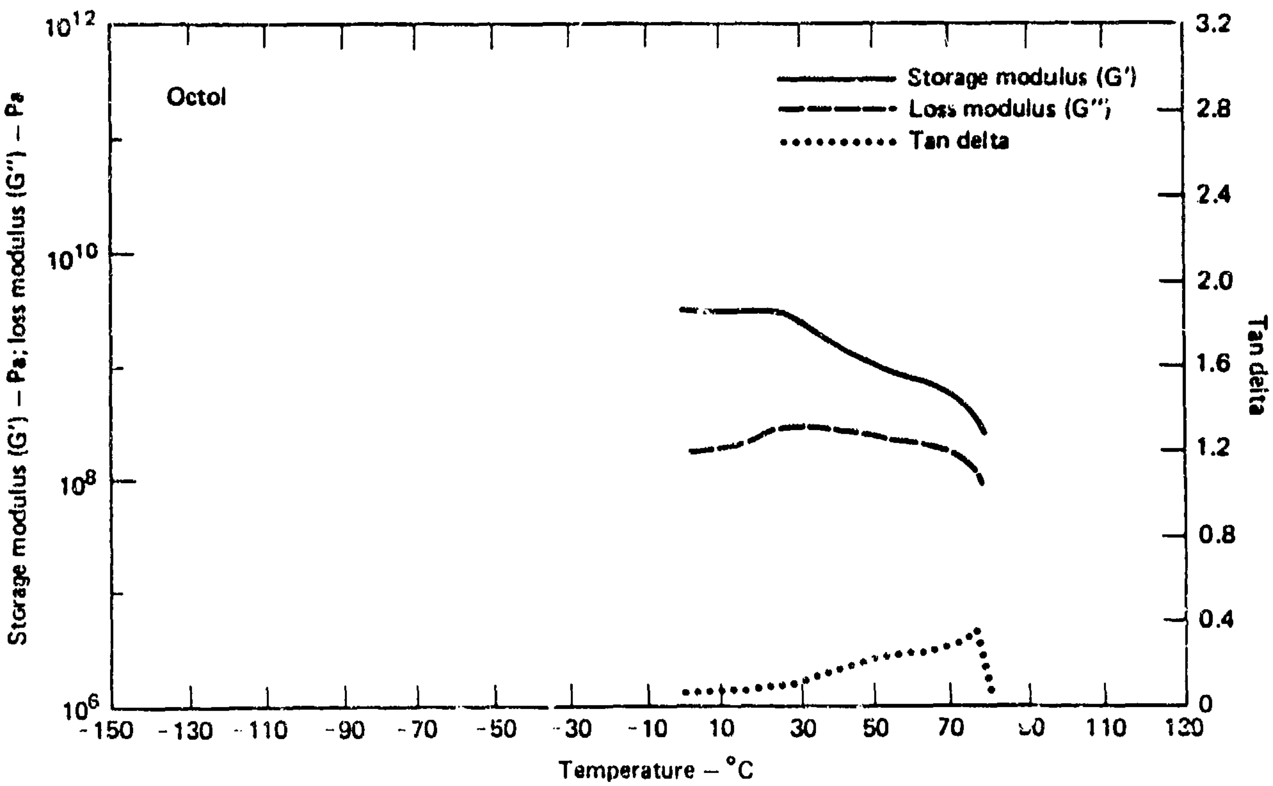


Fig. 7-9h. Values of G', G'', and tan δ for Octol measured with the RMS at 1 Hz.[9]

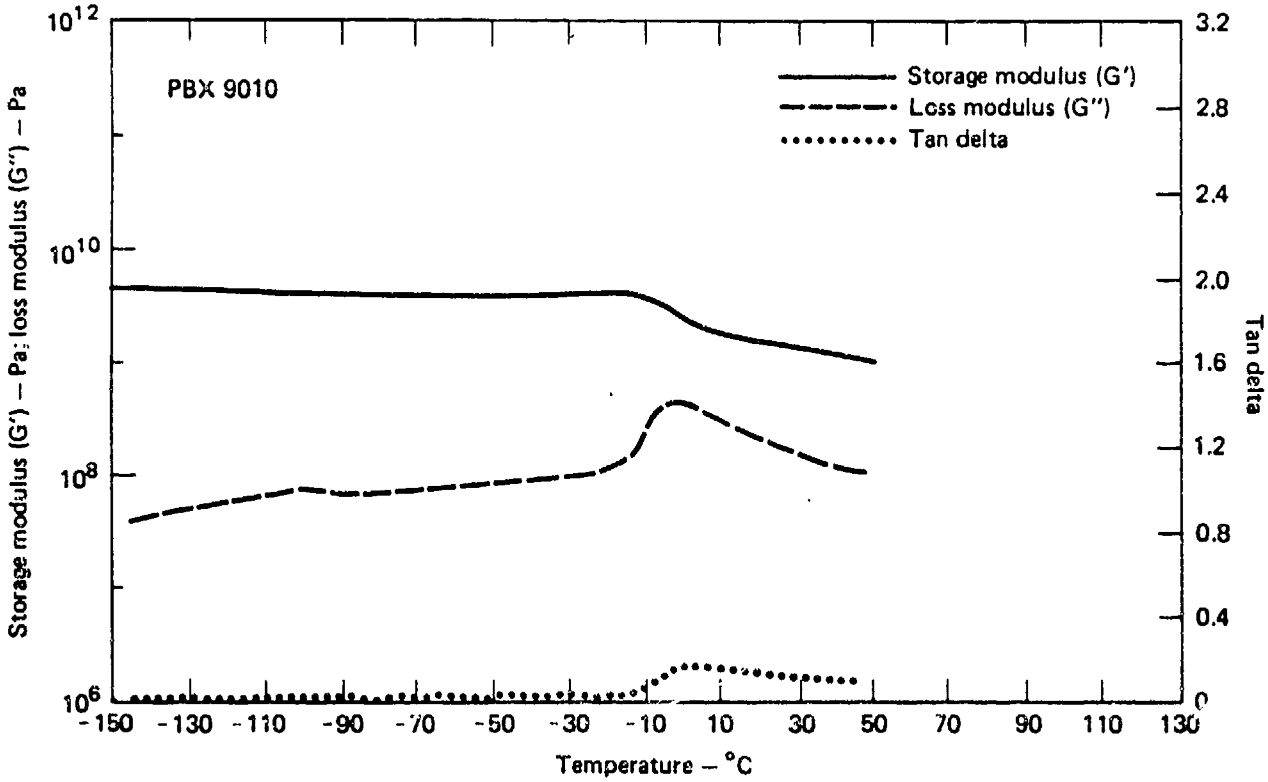


Fig. 7-9i. Values of G', G'', and tan δ for PBX-9010 measured with the RMS at 1 Hz.[9]

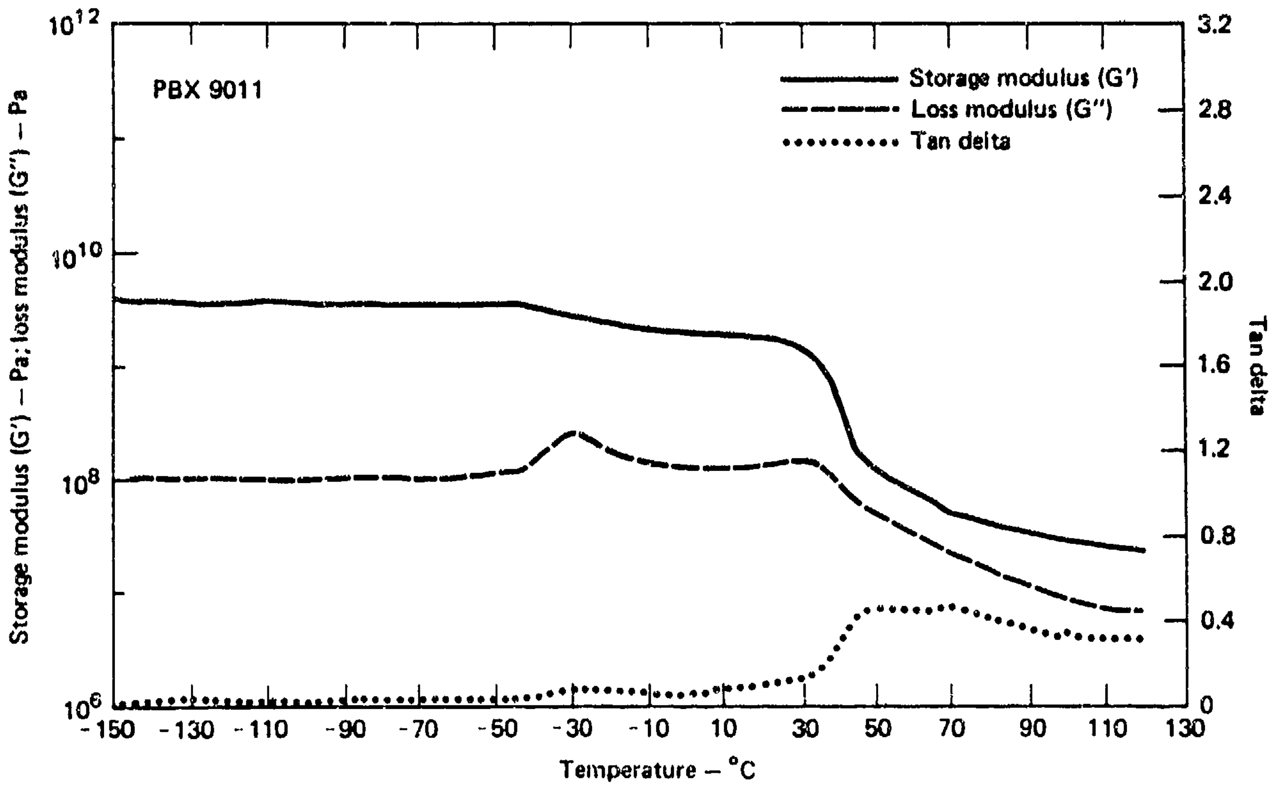


Fig. 7-9j. Values of G', G'', and tan δ for PBX-9011 measured with the RMS at 1 Hz.[9]

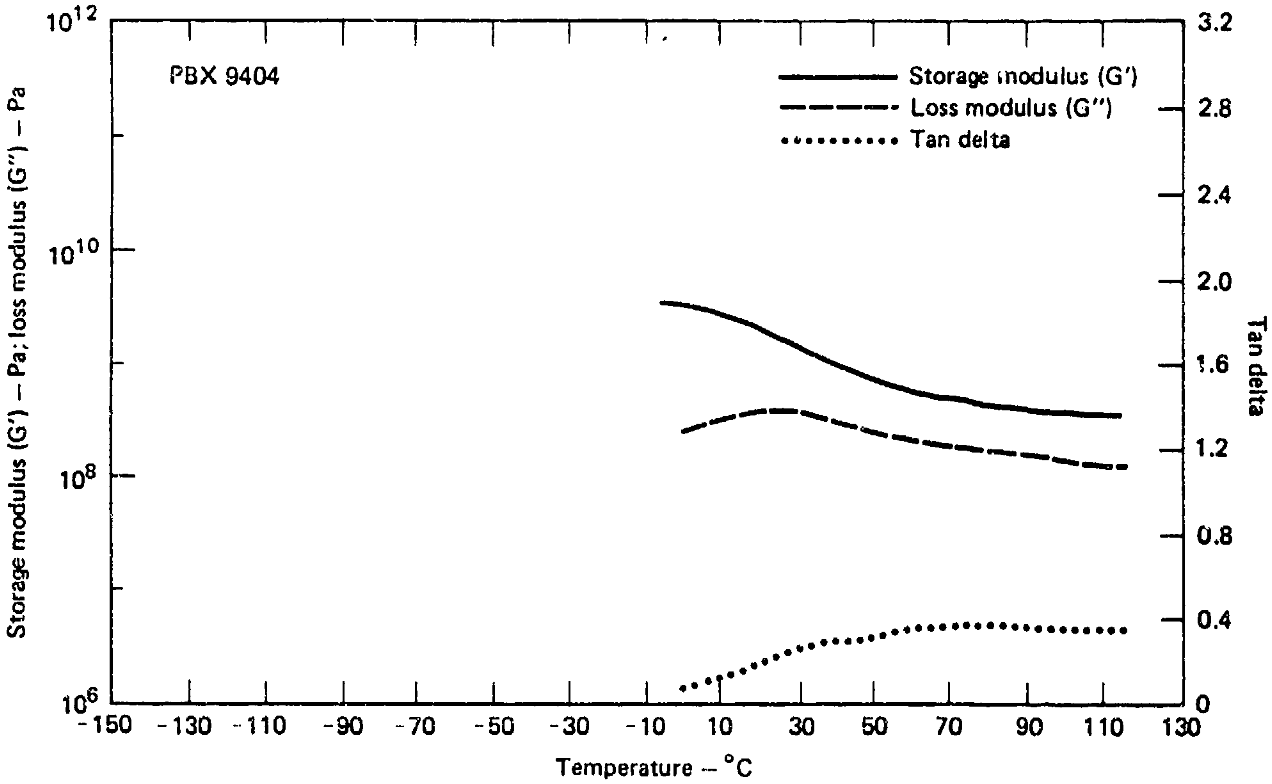


Fig. 7-9k. Values of G', G'', and tan δ for PBX-9404 measured with the RMS at 1 Hz.[9]

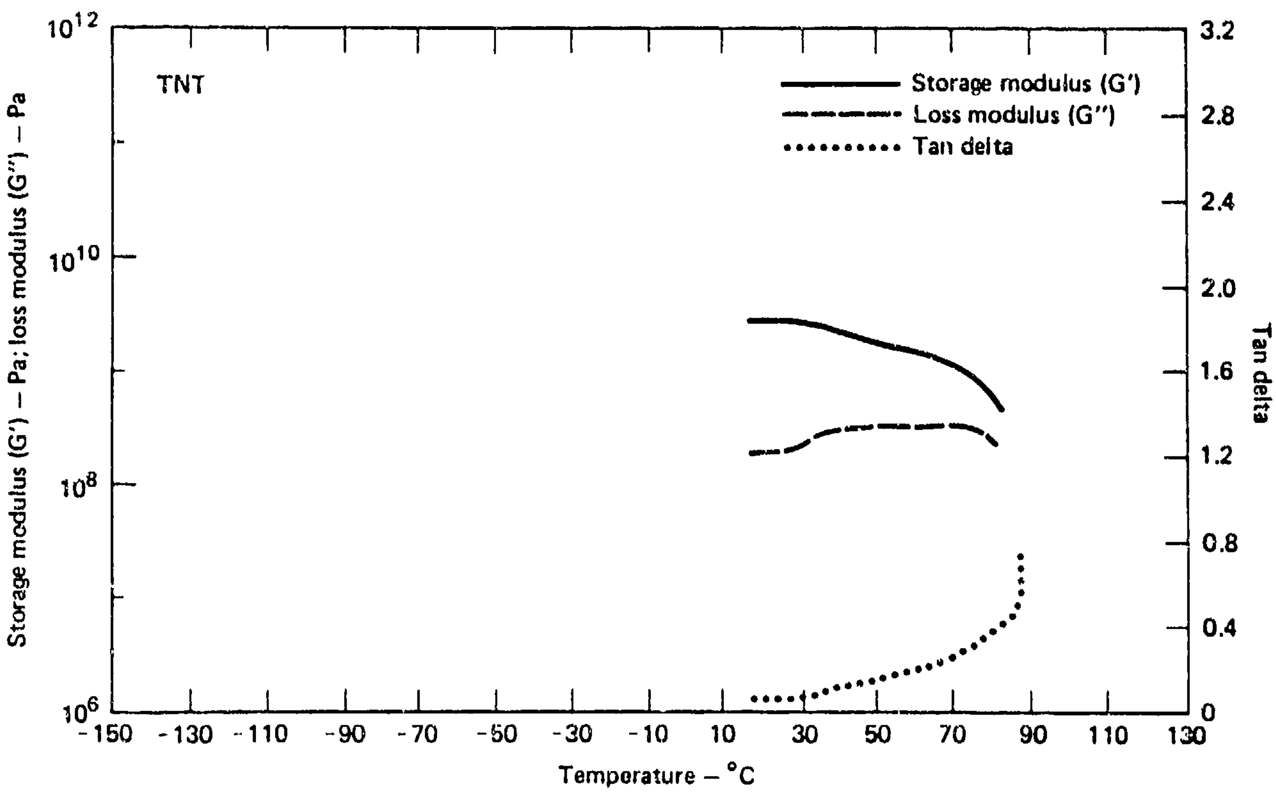


Fig. 7-9l. Values of G', G'', and tan δ for TNT measured with the RMS at 1 Hz.[9]

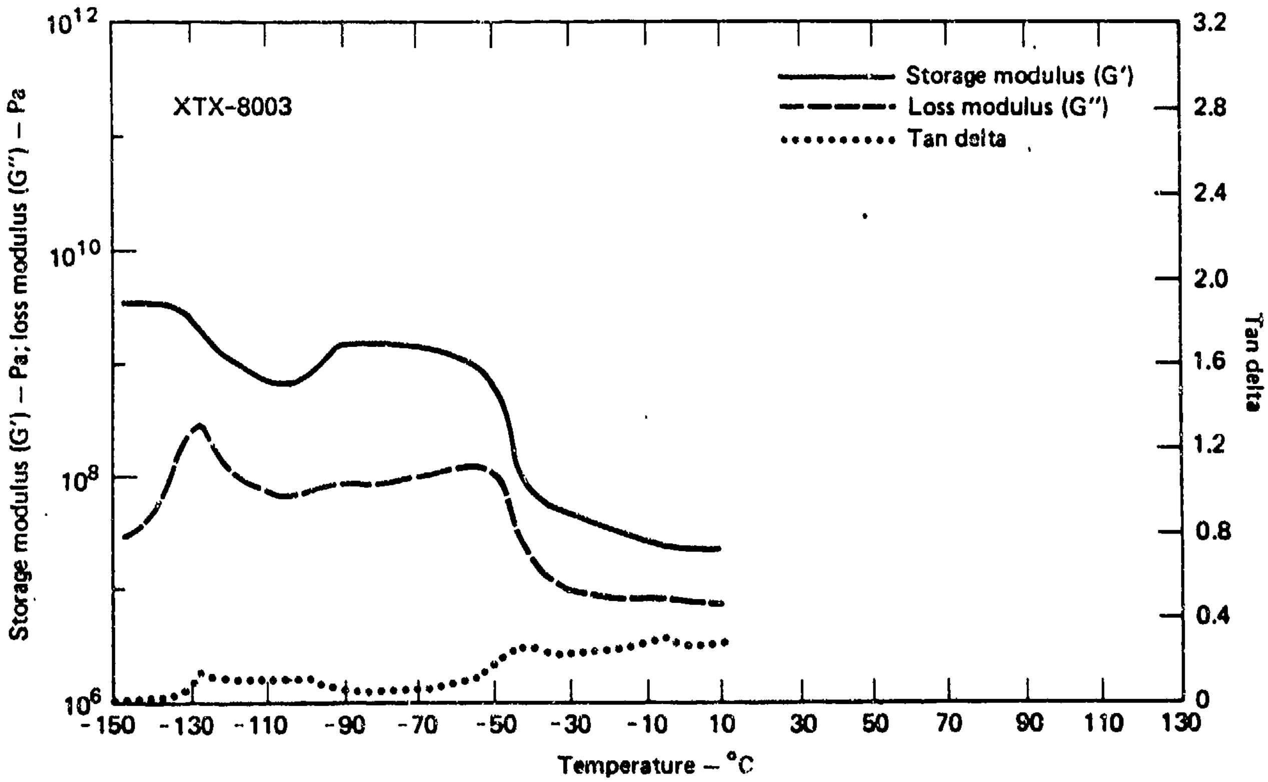


Fig. 7-9m. Values of G', G'', and tan δ for XTX-8003 measured with the RMS at 1 Hz.[9]

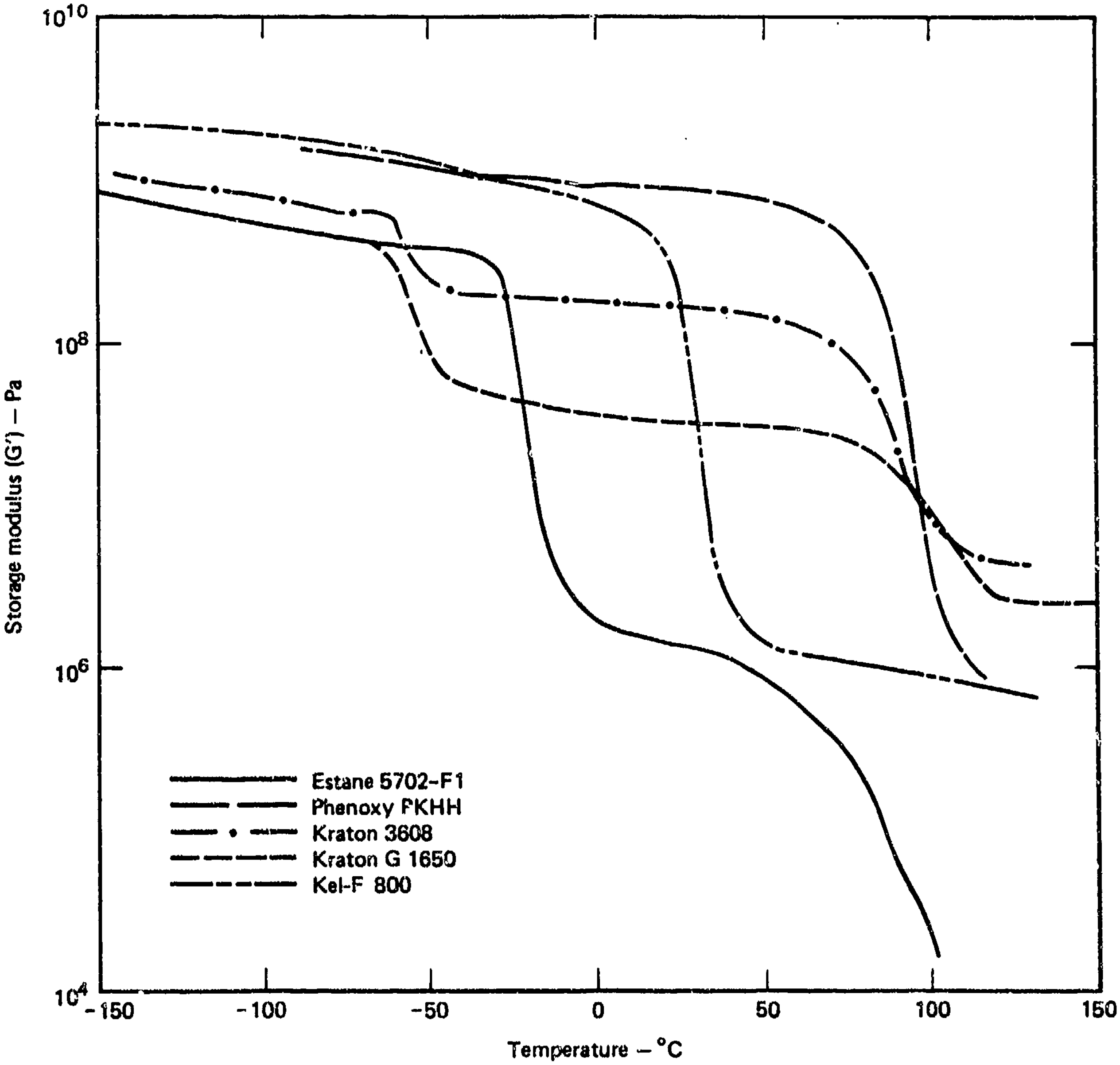


Fig. 7-10. Values of G' for polymeric binders measured with the RMS at 1 Hz.[9]

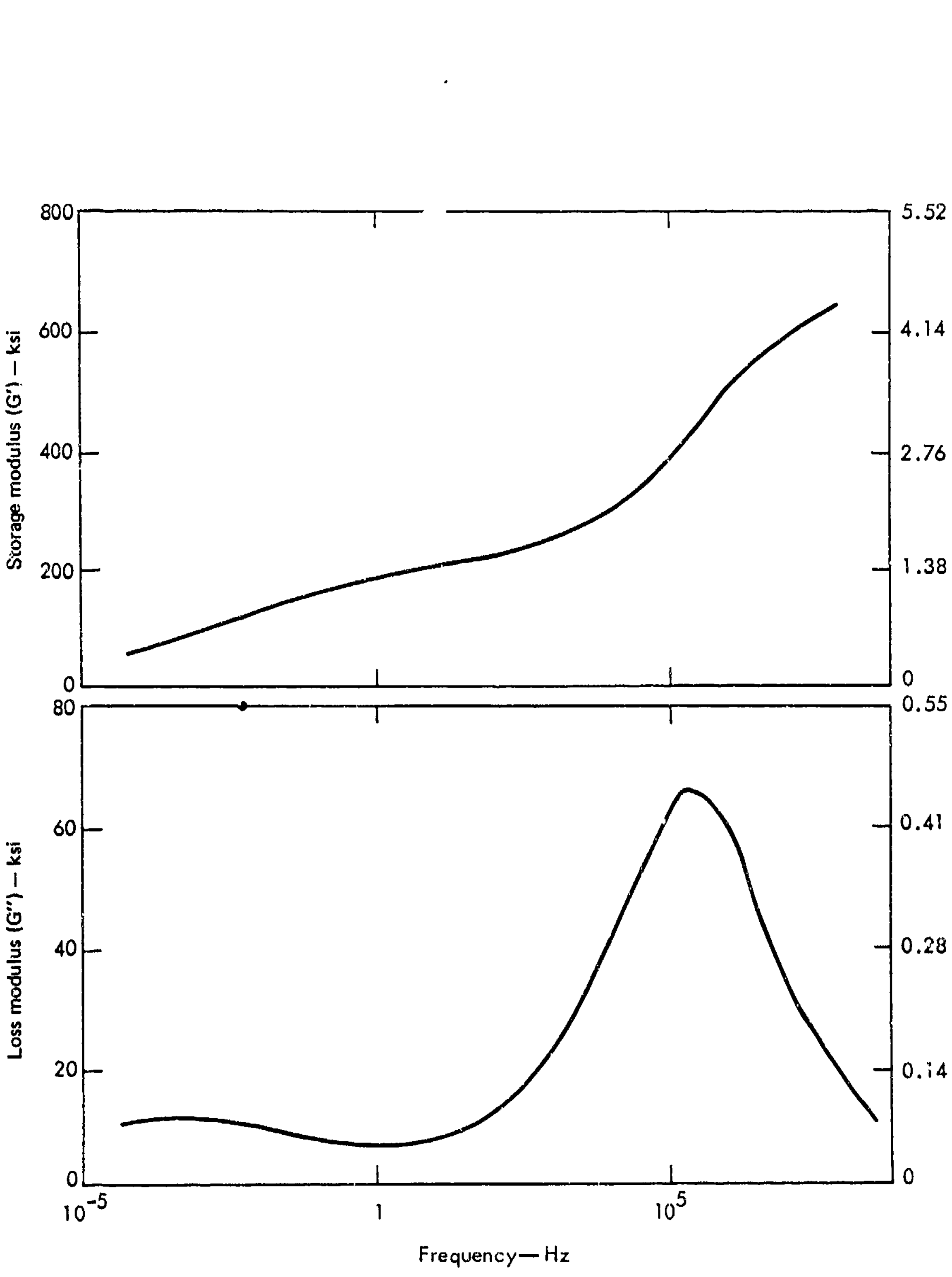


Fig. 7-11. Complex shear moduli of LX-04 at frequencies from 0.0004 to 1 GHz measured and calculated for T_r of 22°C (295 K) over the temperature range -15 to 125°F (247 to 325 K).[10] Conversion factor: 1 psi = 6.895 kPa.

7.3. FRICTION

Static and kinematic coefficients of friction have been determined for various HEs sliding on themselves and on surfaces of different materials.

7.3.1. Static coefficient of friction

A static test was designed to simulate conditions found in the fabrication of explosive assemblies.[11] The sample was placed on a tilt table, and the angle at which it would slide was measured. The coefficient of static friction is defined as the tangent of the angle of inclination from the horizontal plane at which th body just overcomes the frictional force. The results are reported for dry and water-wet surfaces in Table 7-2.

7.3.2. Kinematic coefficient of friction

Kinematic coefficients of friction (f) have been obtained by sliding several HEs on themselves and on aluminum 6061-T6. Values of f were determined as functions of sliding velocity (ν), pressure (load) (P), temperature, and surface finish (Tables 7-3 and 7-4). It was found that the Williams-Landel-Ferry (WLF) shift equation[12] could be used to correlate the effects of sliding velocity and temperature on f; thus, a curve could be calculated for some reduced temperature T_r (Fig. 7-12.)

For comparison, Viton sliding on polished steel at 900 in./min has a coefficient of friction at room temperature of about 0.35 under a 9-kg load and about 0.45 under 18 kg.[45]

Table 7-2. Coefficients of static friction.[11]

		Contact Surface and Roughness														
		Dry							Wet							
		Aluminum		Plexiglas			Mild Steel		Aluminum		Plexiglas			Mild Steel	
Material	Condition	8	10	1	3	7	10	14	8	10	1	3	7	10	14
LX-04:	Pressed	0.425	0.388	0.231	0.538	0.310	0.355	0.200	0.645	0.574	0.771	0.823	0.701	0.361	0.306
	Machined	0.442	0.315	0.422	0.290	0.419	0.388	0.259	0.978	0.747	1.246	0.727	0.671	0.384	0.341
LX-07:	Pressed	0.397	0.391	0.315	0.348	0.341	0.287	0.237	0.514	0.901	1.725	1.706	0.617	0.459	0.381
	Machined	0.474	0.371	0.315	0.528	0.449	0.359	0.213	0.674	3.812	1.095	1.948	0.834	0.537	0.354
LX-10:	Pressed	0.474	0.446	0.723	0.661	0.500	0.361	0.231	0.635	0.621	0.945	1.544	0.729	0.378	0.351
	Machined	0.453	0.328	0.348	0.243	0.515	0.354	0.249	0.519	0.659	0.899	1.480	0.813	0.408	0.332
LX-14:	Pressed	0.391	0.335	0.418	0.391	0.517	0.338	0.216	0.502	0.402	0.648	1.381	0.565	0.281	0.185
	Machined	0.481	0.495	0.520	0.354	0.397	0.287	0.243	0.441	0.634	0.557	0.579	0.544	0.315	0.252
PBX-9404:	Pressed	0.339	0.210	0.240	0.462	0.268	0.210	0.185	0.351	0.441	0.515	1.238	0.447	0.243	0.210
	Machined	0.371	0.281	0.185	0.361	0.325	0.210	0.159	0.542	0.915	0.672	0.696	0.538	0.303	0.228
PBX-9407:	Pressed	0.351	0.284	0.191	0.228	0.284	0.222	0.155	0.439	0.463	0.728	0.949	0.401	0.234	0.191
	Machined	0.351	0.284	0.155	0.354	0.290	0.231	0.176	0.408	0.338	0.290	0.246	0.323	0.237	0.188
PBX-9501:	Pressed	0.328	0.252	0.325	0.335	0.348	0.293	0.219	0.408	0.890	1.601	2.709	1.006	0.569	0.416
	Machined	0.418	0.404	0.415	0.470	0.388	0.197	0.161	0.467	0.662	1.095	0.415	0.518	0.341	0.300
PBX-9502:	Pressed	0.243	0.243	0.197	0.315	0.259	0.191	0.144	0.368	0.729	1.228	0.715	0.496	0.222	0.243
	Machined	0.256	0.207	0.201	0.216	0.253	0.194	0.129	0.458	1.012	1.253	0.845	0.425	0.216	0.271

Table 7-3. Coefficients of friction (f) as functions of sliding velocity ν and pressure P at room temperature.[13]

		Coefficient of friction (f)														
		when $\nu = 10^{-2}$ in./min[a]					when $\nu = 10^{-1}$ in./min[a]					when $\nu = 10^{0}$ in./min[a]				
		at P [psi (MPa)]					at P [psi (MPa)]					at P [psi (MPa)]				
Explosive	Material[b]	125 (0.86)	250 (1.7)	500 (3.5)	750 (5.2)	1000 (6.9)	125 (0.86)	250 (1.7)	500 (3.5)	750 (5.2)	1000 (6.9)	125 (0.86)	250 (1.7)	500 (3.5)	750 (5.2)	1000 (6.9)
Comp B-3/Al	1		0.38	0.36		0.35		0.36	0.33		0.31		0.35	0.34		0.31
	2		0.31	0.30		0.29		0.28	0.27		0.26		0.27	0.265		0.26
Comp B-3/ Comp B-3	1		0.33	0.32				0.33	0.32				0.32	0.31		0.30
	2		0.24	0.23				0.25	0.24				0.26	0.24		0.23
LX-04/Al	1		0.75	0.72				0.81	0.76				0.80	0.74	0.73	
	2		0.70	0.67	0.62			0.69	0.67	0.62			0.65	0.72	0.57	
LX-04/LX-04	1		0.95	0.90				0.98	0.93				1.3	0.94		
	2		0.86	0.83				0.90	0.88				0.94	0.91		
PBX-9011/Al	1		0.71	0.68				0.73					0.74			
	2		0.58	0.52				0.61	0.59				0.62	0.59		
PBX-9011/ PBX-9011	1	0.94	0.92				0.98	0.95				1.1	0.98			
	2	0.90	0.87				0.94	0.90				0.95	0.92			

Table 7-3. Coefficients of friction (f) as functions of sliding velocity v and pressure P at room temperature.[13] (Continued)

		Coefficient of friction (f)														
		when $v = 10^1$ in./min[a] at P [psi (MPa)]					when $v = 10^2$ in./min[a] at P [psi (MPa)]					when $v = 10^3$ in./min[a] at P [psi (MPa)]				
Explosive	Material[b]	125 (0.86)	250 (1.7)	500 (3.5)	750 (5.2)	1000 (6.9)	125 (0.86)	250 (1.7)	500 (3.5)	750 (5.2)	1000 (6.9)	125 (0.86)	250 (1.7)	500 (3.5)	750 (5.2)	1000 (6.9)
Comp B-3/Al																
	1		0.35	0.34		0.32		0.37	0.35		0.34		0.39	0.38		
	2		0.28	0.27		0.27		0.30	0.30				0.35	0.34		
Comp B-3/	1		0.31	0.30		0.28		0.31	0.30		0.29			0.33		
Comp B-3	2		0.265	0.25		0.24			0.27					0.285		
LX-04/Al	1		0.75	0.71	0.69			0.73	0.71	0.69			0.73	0.72		
	2		0.63	0.59	0.56			0.61	0.56				0.61	0.58		
LX-04/LX-04	1		1.1	0.91												
	2		0.92	0.89				0.89					0.86			
PBX-9011/Al	1		0.71					0.70					0.72			
	2		0.57	0.51				0.57	0.50				0.54	0.52		
PBX-9011/	1	1.0	0.98													
PBX-9011	2	0.90	0.89				0.89									

[a] One in./min = 4.23×10^{-4} m/s.
[b] 1 is aluminum, surface finish 125; 2 is aluminum, surface finish 32.

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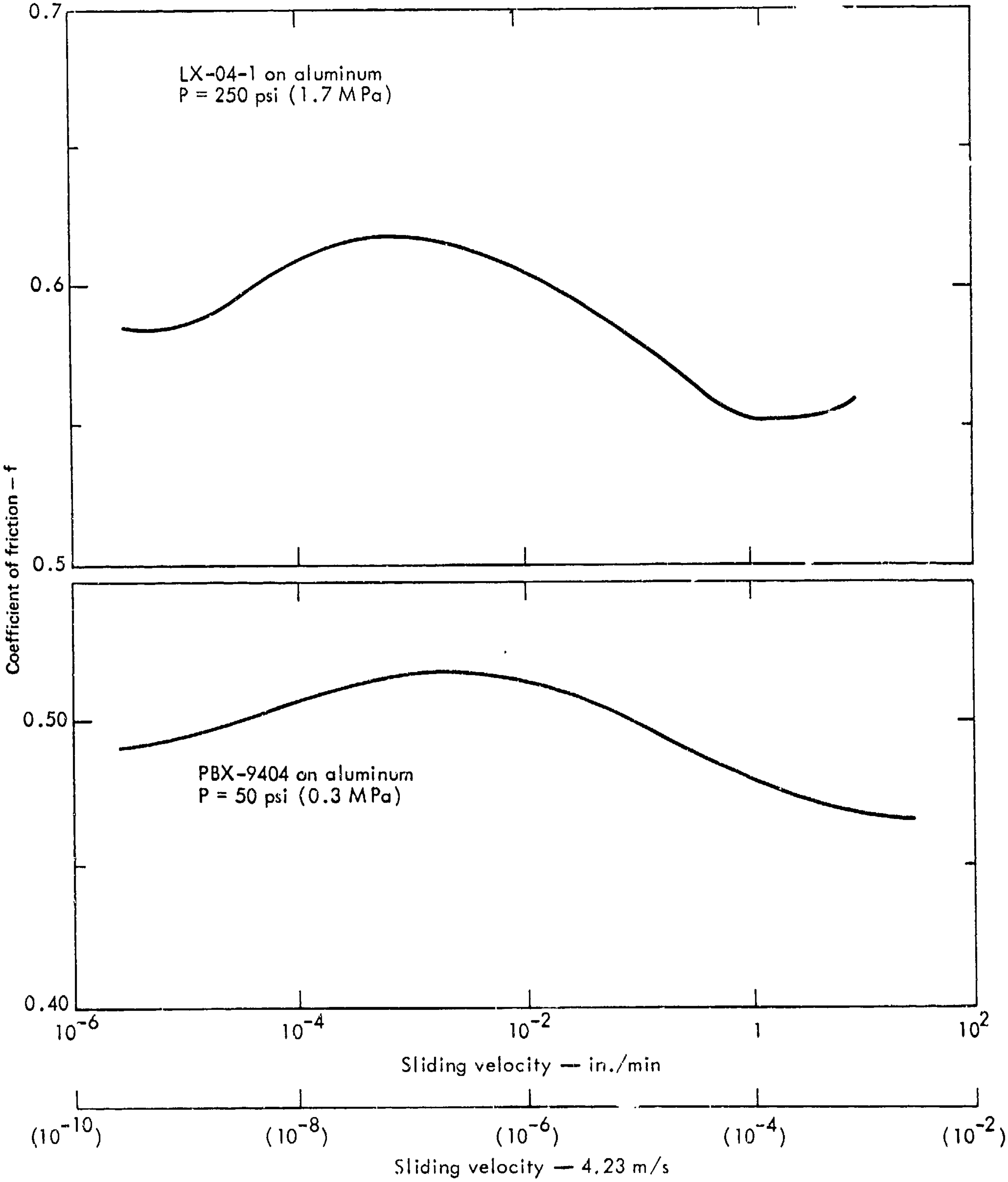


Fig. 7-12. Coefficients of friction (f) for LX-04-1 and PBX-9404 as a function of sliding velocity (ν). Curves calculated for reduced temperatures (T_r) using the Williams-Landel-Ferry (WLF) shift equation.[12] Conversion factor: 1 in./min = 4.23×10^{-4} m/s.

Table 7-4. Coefficients of friction (f) for single crystals of different HEs at constant temperature (20°C) and sliding velocity ($\nu = 2 \times 10^{-4}$ m/s).[14]

Material	f
PETN/glass	0.40
HMX/glass	0.55
RDX/glass	0.35
$Pb(N_3)_2$/glass	0.28
PETN/PETN	0.40

7.4. HUGONIOT DATA

7.4.1. Shock loading

Figures 7-13 and 7-14 show narrow-pulse and sustained shock-loading effects obtained at LANL and LLNL using the flyer-plate technique. The transducer data were normalized to a plate-impact velocity of 0.3 mm/µsec (0.3 km/s) for the LLNL data,[15] while the impact velocities are reported directly for the LANL results.[16]

Figure 7-15 shows representative data from gas gun experiments using dextrinated lead azide.[17]

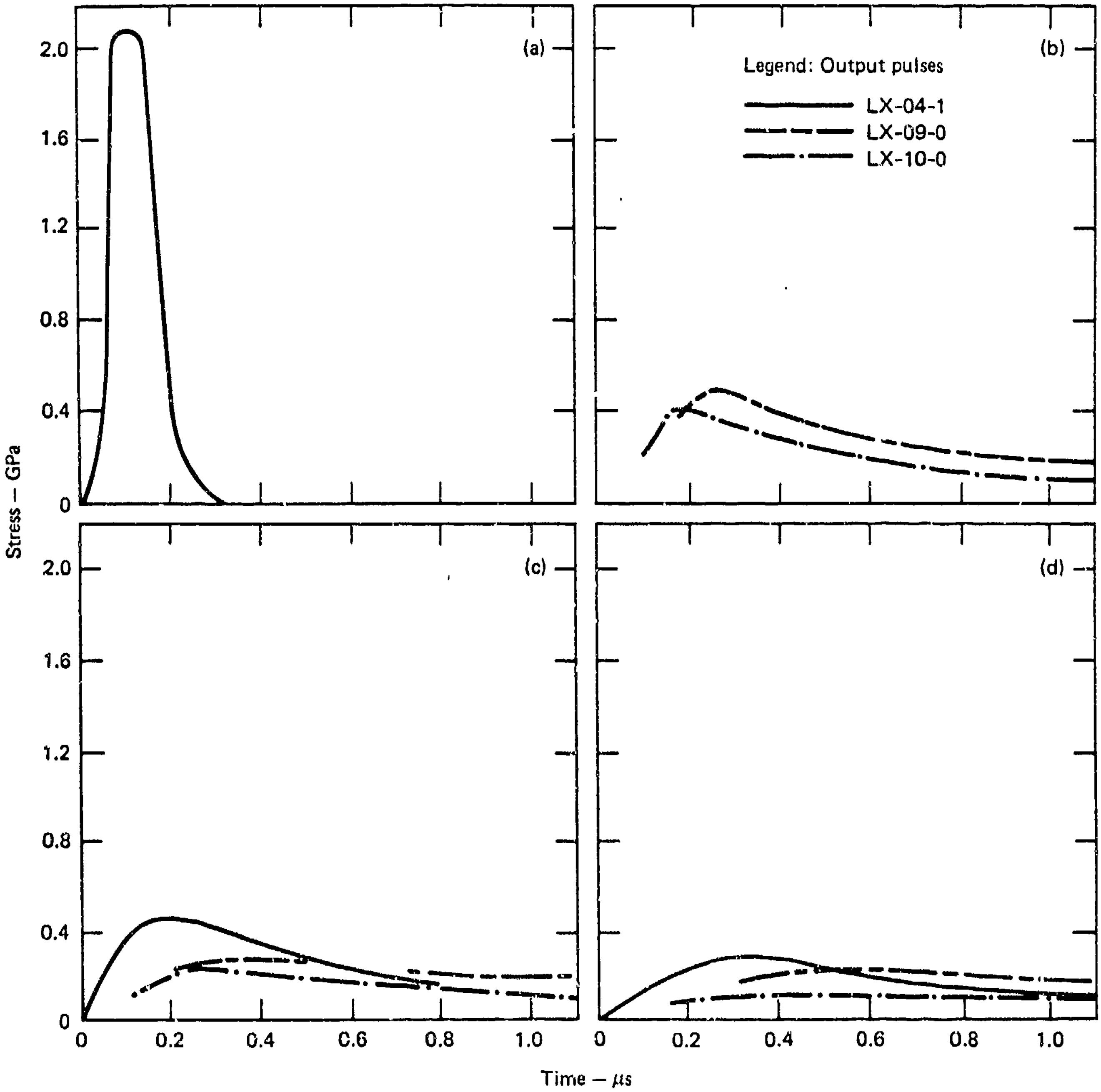


Fig. 7-13. Input and output pulses generated experimentally at three depths in explosives by a 0.28-mm-thick (nominal) aluminum driver plate backed with foam.[15] Conversion factor: 1 bar = 10^5 Pa.

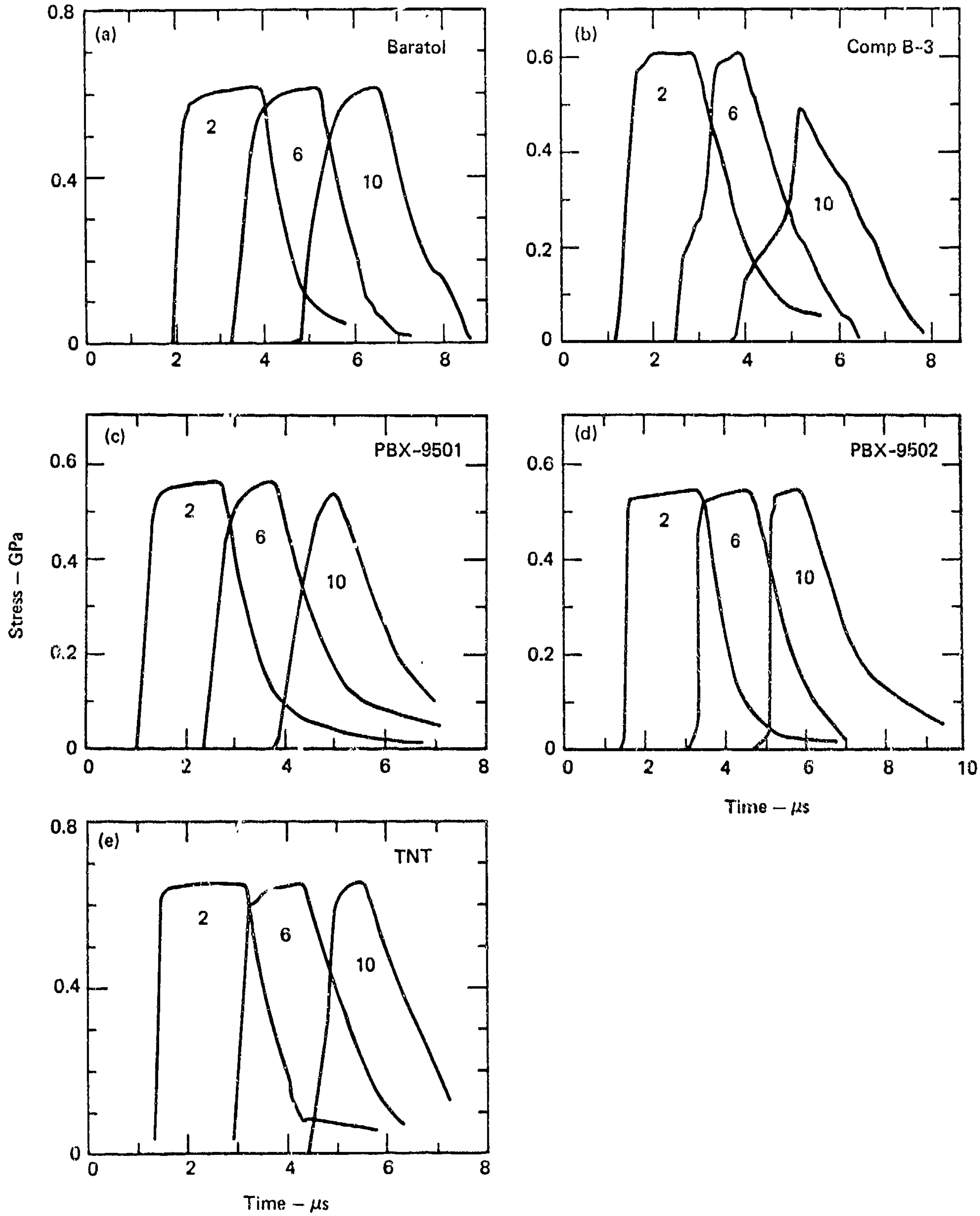


Fig. 7-14. Output pulses generated experimentally at three depths (2, 6, and 10 mm) in different explosives by a 3.05-mm thick aluminum, foam-supported impactor. The impact velocities (km/s) were (a) 0.176, (b) 0.266, (c) 0.248, (d) 0.252, and (e) 0.294.[16]

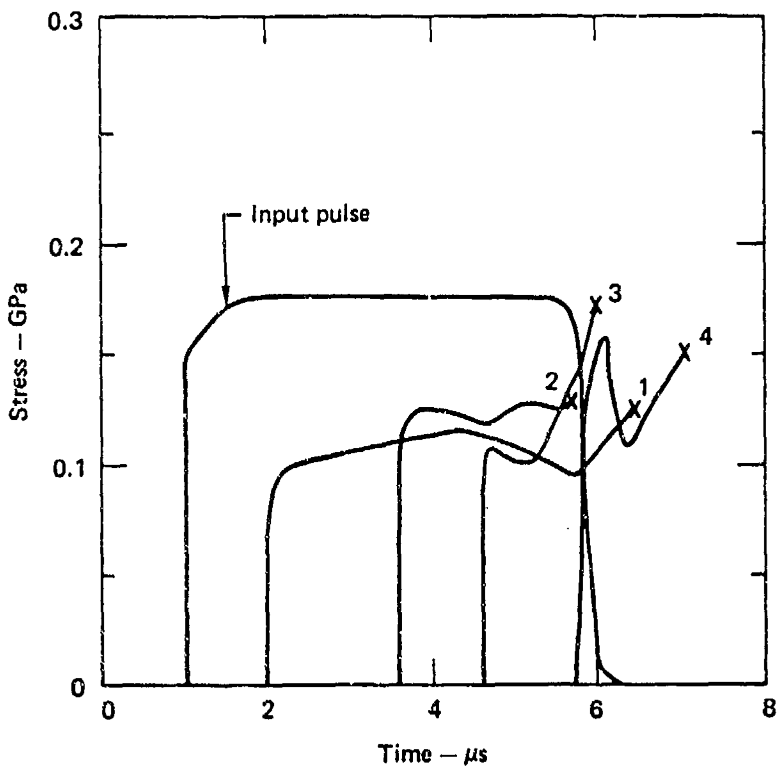


Fig. 7-15. Input and output pulses at four depths in lead azide by a 5.08-mm thick Plexiglas support plate.[17]

7.4.2. Unreacted Hugoniot

The Hugoniot of unreacted HEs can also be expressed by a simple least squares relationship:

$$U_s = A + BU_p - CU_p^2 ,$$

where

U_s = shock velocity in km/s,
U_p = particle velocity in km/s,
A, B, C = materials constants.

The data (at ambient temperature) have been compiled from various sources for the compositions listed in Tables 3-1 to 3-3. The Grüneisen constant γ is expressed as:

$$\gamma = V \left(\frac{\partial P}{\partial E}\right)_V = \frac{V}{C_V} \mathscr{K} \cdot \beta_V ,$$

where

P = pressure,
E = energy,
V = volume,
$\mathscr{K}$ = bulk modulus,
β = cubic coefficient of thermal expansion.

Least squares relationships for unreacted Hugoniots are given in Table 7-5.

Table 7-5. Least squares fits for unreacted Hugoniots.

Explosive	Density, ρ_0 [g/cm^3 (Mg/m^3)]	Equation	Range[a] (km/s)	γ	Ref.
AN	0.86	$U_s = 0.84 + 1.42\ U_p$		0.9	18
	1.73	$U_s = 2.20 + 1.96\ U_p$			18
Baratol	2.611	$U_s = 2.40 + 1.66\ U_p$	$c_0 \le U_s \le 3.66$		19
		$U_s = 1.5 + 2.16\ U_p$	$3.66 \le U_s \le 4.0$		19
	2.63	$U_s = 2.79 + 1.25\ U_p$			20
Comp B	1.70	$U_s = 2.95 + 1.58\ U_p$			20
	1.710	$U_s = 1.20 + 2.81\ U_p$	$4.40 \le U_s \le 5.04$		21
Comp B (cast)	1.700	$U_s = 2.49 + 1.99\ U_p$	$3.57 \le U_s \le 5.02$		21
Comp B-3	1.70	$U_s = 3.03 + 1.73\ U_p$			20
	1.70	$U_s = 2.88 + 1.60\ U_p$	$4.24 \le U_s \le 7.01$ $c_0 = 2.93$		21
	1.72	$U_s = 2.71 + 1.86\ U_p$	$3.42 \le U_s \le 4.45$		21
	1.723	$U_s = 1.23 + 2.81\ U_p$	$4.42 \le U_s \le 5.07$		21
Comp B-3 (cast)	1.680	$U_s = 2.710 + 1.860\ U_p$	$3.387 \le U_s \le 4.469$ $c_0 = 2.736$	0.947	21,22
Cyclotol 75/25	1.729	$U_s = 2.02 + 2.36\ U_p$	$4.67 \le U_s \le 5.22$		21
DATB	1.780	$U_s = 2.449 + 1.892\ U_p$	$3.159 \le U_s \le 4.492$ $c_\ell = 2.660$	1.76	21,22
H-6 (cast)	1.760	$U_s = 2.832 + 1.695\ U_p$	$2.832 \le U_s \le 4.535$ $c_0 = 2.759$		21,22
	1.76	$U_s = 2.654 + 1.984$	$U_s < 3.7$		29
HBX-1 (cast)	1.750	$U_s = 2.936 + 1.651\ U_p$	$c_b = 2.860$		22
HBX-3 (cast)	1.850	$U_s = 3.134 + 1.605\ U_p$	$c_b = 3.095$		22
HMX	1.903	$U_s = 2.74 + 2.6\ U_p$		1.10	23
	1.891	$U_s = 2.901 + 2.058\ U_p$			19
HNS	1.38	$U_s = 0.61 + 2.77\ U_p$	$1.44 \le U_s \le 1.995$		24
	1.57	$U_s = 1.00 + 3.21\ U_p$	$1.00 \le U_s \le 3.18$ $c_0 = 1.00$		24

Table 7-5. Least squares fits for unreacted Hugoniots. (Continued)

Explosive	Density, ρ_0 [g/cm^3 (Mg/m^3)]	Equation	Range[a] (km/s)	γ	Ref.
HNS-II	1.47	$U_s = 1.10 + 3.48\ U_p$			25
	1.58	$U_s = 1.98 + 1.93\ U_p$			25
Kel-F	2.10	$U_s = 1.73 + 1.61\ U_p$	$2.65 \le U_s \le 3.78$		21
LX-04-1	1.860-1.863	$U_s = 2.36 + 2.43\ U_p$	$2.61 \le U_s \le 3.24$		21
LX-09-0	1.839	$U_s = 2.43 + 2.90\ U_p$			26
LX-17-0	1.90	$U_s = 2.33 + 2.32\ U_p$			44
NG	1.59	$U_s = 2.24 + 1.66\ U_p$			28
NM	1.13	$U_s = 2.00 + 1.38\ U_p$	$2.83 \le U_s \le 4.40$		21
	1.123-1.128	$U_s = 1.560 + 1.721\ U_p + 1.082(1.125 - \rho_0)$	$2.918 \le U_s \le 4.639$		21
NQ[b]		$U_s = 3.544 + 1.459\ U_p$			
[c]		$U_s = 3.048 + 1.725\ U_p$			
Octol	1.80	$U_s = 3.01 + 1.72\ U_p$			20
(cast)	1.803	$U_s = 2.21 + 2.51\ U_p$	$3.24 \le U_s \le 4.97$		21
PBX-9011-06	1.790	$U_s = 2.225 + 2.644\ U_p$	$4.1 \le U_s \le 6.1$		19
PBX-9404-03	1.721	$U_s = 1.89 + 1.57\ U_p$	$2.4 \le U_s \le 3.7$		19
	1.84	$U_s = 2.45 + 2.48\ U_p$	$2.45 \le U_s \le 6.05$ $c_0 = 2.60$		24
PBX-9404	1.84	$U_s = 2.310 + 2.767\ U_p$	$U_s < 3.2$ $c_b = 2.310$		29
PBX-9407	1.60	$U_s = 1.328 + 1.993\ U_p$	$2.11 \le U_s \le 3.18$		30
PBX-9501-01	1.844	$U_s = 2.683 + 1.906\ U_p$	$2.9 \le U_s \le 4.4$		19
PBX-9604	1.491	$U_s = 0.987 + 2.509\ U_p$			27
Pentolite 50/50	1.67	$U_s = 2.83 + 1.91\ U_p$			20
	1.676	$U_s = 2.885 + 3.20\ U_p$	$4.52 \le U_s \le 5.25$		21

Table 7-5. Least squares fits for unreacted Hugoniots. (Continued)

Explosive	Density, ρ_0 [g/cm^3 (Mg/m^3)]	Equation	Range[a] (km/s)	ν	Ref.
PETN	0.82	$U_s = 0.47 + 1.73\ U_p$		1.7	18
	1.59	$U_s = 1.33 + 2.18\ U_p$	$1.40 \le U_s \le 2.14$ $c_0 = 2.45$		24
		$U_s = 0.64 + 4.19\ U_p$	$1.86 \le U_s \le 2.65$ $c_0 = 2.45$		24
	1.60	$U_s = 1.32 + 2.58\ U_p$	$1.89 \le U_s \le 2.56$	0.77	31
	1.72	$U_s = 2.326 + 2.342\ U_p$	$2.83 \le U_s \le 3.18$ $c_b = 2.326$		32
		$U_s = 1.83 + 3.45\ U_p$	$2.52 \le U_s \le 3.87$ $c_b = 2.24$	0.77	31
	1.75	$U_s = 2.53 + 1.88\ U_p$			33
	1.77	$U_s = 2.42 + 1.91\ U_p$			18
	1.774	$U_s = 2.320 + 2.61\ U_p - 0.38 U_p^2$	$U_s < 4.1648$ $c_b = 2.32$		34
		$U_s = 2.811 + 1.73\ U_p$	$U_s > 4.195$	1.15	34
Polystyrene	1.05	$U_s = 2.40 + 1.637\ U_p$	$3.87 \le U_s \le 6.493$		21
RDX	1.0	$U_s = 0.4 + 2.00\ U_p$		2.6	18
	1.64	$U_s = 1.93 + 0.666\ U_p$	$2.00 \le U_s \le 2.16$ $c_0 = 2.80$		24
		$U_s = 0.70 + 4.11\ U_p$	$2.14 \le U_s \le 2.63$ $c_0 = 2.80$		24
	1.799	$U_s = 2.78 + 1.9\ U_p$		1.29	23
	1.80	$U_s = 2.87 + 1.61\ U_p$	$4.21 \le U_s \le 5.45$		19
TATB	1.847	$U_s = 2.340 + 2.316\ U_p$	$3.125 \le U_s \le 5.629$ $c_0 = 2.050$	1.60	20,21 22,26
	1.876	$U_s = 1.46 + 3.68\ U_p$	$c_0 \le U_s \le 3.23$		19
		$U_s = 2.037 + 2.497\ U_p$	$3.23 \le U_s \le 5.9$		19
	1.937	$U_s = 1.43 + 10.13\ U_p - 11.42\ U_p^2$	$U_s < 3.4412$		33
		$U_s = 2.90 + 1.68\ U_p$	$U_s > 3.404$ $c_b = 1.43$	0.20	33

Table 7-5. Least squares fits for unreacted Hugoniots. (Continued)

Explosive	Density, ρ_0 [g/cm^3 (Mg/m^3)]	Equation	Range[a] (km/s)	γ	Ref.
Tetryl	0.86	$U_s = 0.35 + 1.75\ U_p$		1.65	18
	1.30	$U_s = 2.1620 + 1.4271\ U_p - (0.4993/U_p)$	$2.58 \leq U_s \leq 4.16$ $c_\ell = 1.1$		35
	[illegible]	$U_s = 1.6111 + 1.9658\ U_p - (0.2784/U_p)$	$2.20 \leq U_s \leq 4.07$ $c_\ell = 1.13$		35
	1.50	$U_s = 2.1674 + 1.6225\ U_p - (0.3411/U_p)$	$2.63 \leq U_s \leq 4.17$ $c_\ell = 1.36$		35
	1.60	$U_s = 2.3621 + 1.5285\ U_p - (0.2519/U_p)$	$2.86 \leq U_s \leq 4.25$ $c_\ell = 1.66$		35
	1.70	$U_s = 2.4763 + 1.416\ U_p$	$3.08 \leq U_s \leq 4.17$ $c_\ell = 2.035$		35
	1.73	$U_s = 2.17 + 1.91\ U_p$			18
TNT	0.98	$U_s = 0.366 + 1.813\ U_p$	$1.05 \leq U_s \leq 3.26$		18
	1.643-1.648	$U_s = 2.372 + 2.16\ U_p$	$2.78 < U_s$ $c_0 = 2.30$		21
			$2.345 \leq U_s \leq 3.375$		
cast	1.614	$U_s = 2.390 + 2.050\ U_p$	$3.034 < U_s < 5.414$ $c_0 = 2.572$	0.737	21,22
	1.62	$U_s = 2.274 + 2.652\ U_p$	$U_s < 3.7$		29
		$U_s = 2.987 + 1.363\ U_p$	$3.7 < U_s$ $c_\ell = 2.297$		29
	1.63	$U_s = 2.57 + 1.88\ U_p$			20
(liquid) (82°C)	1.472	$U_s = 2.14 + 1.57\ U_p$	$3.49 \leq U_s \leq 4.65$ $c_0 = 1.37$		21,22
Tritonal (cast)	1.73	$U_s = 2.313 + 2.769\ U_p$	$U_s < 3.8$		29
XTX-8003	1.53	$U_s = 1.49 + 3.30\ U_p$	$2.38 \leq U_s \leq 4.06$	0.77	31

[a] Sound velocities through the sample are in km/s; c_0 = initial sound velocity, c_ℓ = longitudinal sound velocity, c_b = bulk sound velocity. Pressures were converted to pascal.
[b] Large grain.
[c] Commercial grain.

7.4.3. Sound velocity

Longitudinal and transverse shear sound velocities (c_ℓ and c_s, respectively) were measured bv Marsh of LANL for materials with large acoustic attenuation.[36] The arrival times of signals traveling through different thicknesses of stacked samples were measured, and the sound velocities were determined by a differential technique, i.e., by measuring the transit times of the signals through the measured thicknesses of the samples.

The bulk sound velocities (c_b) compiled in Table 7-6 were determined from the expression for isotropic materials:

$$c_b = \sqrt{c_\ell^2 - \frac{4}{3} c_s^2} .$$

Table 7-6. Sound velocities c_ℓ, c_s, and c_b.

Material (preparation)	Density, ρ [g/cm^3 (Mg/m^3)]	c_ℓ (km/s)	c_s (km/s)	c_b (km/s)	Ref.
AP (bulk, 500 μ)	1.20	0.57	--	--	37
	1.55	1.79	--	--	37
	1.90	2.18	--	--	37
AP (bulk)	1.95	--	--	2.84	38
Baratol	2.61	2.90	1.54	2.29	16
(cast)	2.611	2.95	1.48	2.40	36
Comp B-3	1.70	3.00	1.62	2.35	16
(cast)	1.726	3.12	1.71	2.42	36
Cyclotol 75/25 (cast)	1.752	3.12	1.69	2.43	36
DATB (pressed)	1.78	2.99	1.55	2.40	36
Estane	1.18	--	--	2.35	39
H-6	1.75	2.46	1.55	--	40
HNAB	1.577	0.853	0.465	0.663	41
Kel-F	2.02	--	--	1.50	39
LX-15-0	1.58	1.749	1.038	1.274	41
LX-17-0	1.899	2.815	1.366	2.24	43
NM	1.14	--	--	1.33	38
Octol (cast)	1.80	3.14	1.66	2.49	36
PBX-9010-02	1.78	2.72	1.47	2.13	36
PBX-9011-06	1.790	2.89	1.38	2.41	36
PBX-9404-03	1.840	2.90	1.57	2.26	36
PBX-9407	1.78	3.04	1.70	2.32	36
	1.608	1.922	1.26	1.256	41

Table 7-6. Sound velocities c_ℓ, c_s, and c_b. (Continued)

Material (preparation)	Density, ρ [g/cm³ (Mg/m³)]	c_ℓ (km/s)	c_s (km/s)	c_b (km/s)	Ref.
PBX-9501	1.82	2.97	1.39	2.50	16
PBX-9502	1.88	2.74	1.38	2.20[a]	16
PBX-9604	1.491	--	--	0.996	27
PETN	1.77	--	--	2.32	38
Polystyrene	1.06	--	--	1.98	38
RDX (pressed)	1.80	--	--	2.65	38
TATB	1.868	1.907	1.083	1.439	41
(pressed)	1.87	2.00[b]	1.18[b]	1.43[f]	16,42
	1.87	2.55[c]	--	1.43[f]	16,42
	1.87	--	1.24[d]	1.43[f]	16,42
	1.87	--	1.35[e]	1.43[f]	16,42
(isotropic purified)	1.876	1.98	1.16	1.46	36
Tetryl	1.73	--	--	2.19	38
(pressed)	1.68	2.27	1.24	1.76	36
TNT	1.63	2.68	1.35	2.1[illegible]	16
(creamed, cast)	1.624	2.48	1.34	--	16
(crystal)	--	--	--	2.20	38
(liquid)	1.47	--	--	1.55	38
(molten)	1.47	--	--	2.1	36
(pressed)	1.61	2.48	1.34	1.94	36
(pressed)	1.632	2.58	1.35	2.08	36

[a] No check was made of other sample orientations.
[b] Parallel to pressing direction.
[c] Perpendicular to pressing direction.
[d] Perpendicular to pressing direction and particle motion parallel to pressing direction.
[e] Perpendicular to pressing direction and particle motion perpendicular to pressing direction.
[f] Assuming that TATB is transverse isotropic, the velocities were converted to elastic constants from which the bulk sound speed was calculated.

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8. PERFORMANCE

This section contains tables of detonation velocities and methods for their estimation, detonation velocity equations, Chapman-Jouguet detonation pressures, reaction-zone lengths, cylinder test measurements of explosive energies, equation-of-state parameters, detonation energies, Gurney values, and failure diameters.

8.1. DETONATION VELOCITY

Detonation velocities (D) can be determined experimentally (Table 8-1), calculated for variations in composition and temperature, or estimated with the use of empirical relationships.

Table 8-1. Detonation velocities (D) measured at nominal composition and density ρ, under ambient conditions in large charges.

Explosive	Density, ρ [g/cm^3 (Mg/m^3)]	Detonation velocity, D [mm/μsec (km/s)][a]	Ref.
Amatol 80/20	1.6	5.2	1
AN	~0.7	~1.5	2
	0.82	3.49 (in paper tubes)	3
	1.30	5.27 (in paper tubes)	3
Baratol	2.55	4.87	
Black powder	~0.7	~1.3	2
	~0.9-1.1	~1.35	2
Boracitol	1.55	4.86	
BTF	1.86	8.49	
Comp A-3	1.61	8.27	4
	1.64	8.47	5
Comp B	1.56	7.48 (in paper tubes)	3
	1.61	7.67	4
(cast)	1.72	7.92	5

Table 8-1. Detonation velocities D measured at nominal composition and density ρ, under ambient conditions in large charges. (Continued)

Explosive	Density, ρ [g/cm^3 (Mg/m^3)]	Detonation velocity, D [mm/μsec (km/s)][a]	Ref.
Comp B, Grade A (pressed)	1.72	7.99	
Comp B-3 (cast)	1.62	7.70	
	1.72	7.89	5
Comp C-3	1.60	7.63	8
Comp C-4	1.59	8.04	8
	1.601	8.19	
	1.66	8.37	5
Cyclotol 60/40	1.72	7.90	8
Cyclotol 75/25	1.74	8.20	5
	1.76	8.30	8
DATB	1.79	7.52	
DEGN	1.38	6.76	8
DIPAM	1.76	7.40	6
EL-506A	1.48	7.0	
EL-506C	1.48	7.03	7
Explosive D	1.55	6.85	8
FEFO	1.607	7.50	
H-6	1.71	7.19	8
	1.75	7.9	9
HBX-1	∿1.60	5.38	10
	1.712	7.31	10
HBX-3	1.81	6.92	8
	1.84	7.12	5
HMX	1.89	9.11	
HNAB (pressed)	1.60	7.311	11

Table 8-1. Detonation velocities D measured at nominal composition and density ρ, under ambient conditions in large charges. (Continued)

Explosive	Density, ρ [g/cm^3 (Mg/m^3)]	Detonation velocity, D [mm/μsec (km/s)][a]	Ref.
HNS I	1.60	6.80	6,12
HNS II	1.70	7.00	6,12
Lead azide	3.8	5.5	13
Lead styphnate	2.9	5.2	
LX-01	1.24	6.84	
LX-02	1.44	7.37	
LX-04	1.86 1.87	8.46 8.54	5
LX-07-2	1.87	8.64	
LX-08	≥1.42	6.56	
LX-09-1	1.84	8.81	14
LX-10-0	1.86	8.82	
LX-10-1	1.87	8.85	14
LX-11	1.87	8.32	
LX-13 (See XTX-8003)			
LX-14-0	1.835	8.83	15
LX-15	1.584	6.84	16
LX-17-0	1.903	7.63	30
MEN-II	1.02	5.49	
Minol-2	1.68	5.82	8
NC (13.45% N)	1.20	7.30	
NG	1.59 1.60	7.65 7.70	17

Table 8-1. Detonation velocities D measured at nominal composition and density ρ, under ambient conditions in large charges. (Continued)

Explosive	Density, ρ [g/cm^3 (Mg/m^3)]	Detonation velocity, D [mm/μsec (km/s)][a]	Ref.
NM	1.13	6.35	18
NQ	1.55	7.65	
	1.62	7.93	36
Octol 75/25	1.81	8.48	
PBX-9007	1.64	8.09	
PBX-9010	1.78	8.37	
PBX-9011	1.77	8.50	
PBX-9205	1.67	8.17	
PBX-9404	1.84	8.80	
PBX-9407	1.60	7.91	
PBX-9501	1.84	8.83	19
PBX-9502	1.90	7.71	20
PBX-9503	1.90	7.72	21
Pentolite 50/50	1.68	7.52	23
	1.70	7.53	22
PETN	1.6	7.9	1
	1.76	8.26	
Picric acid (cast)	1.6	7.1	1
	1.71	7.26	23
RDX	1.6	8.25	1
	1.77	8.70	
TACOT	1.85	7.25	
TATB	1.88	7.76	
Tetryl (pressed)	1.51	7.15	23
	1.6	7.5	1
	1.71	7.85	

Table 8-1. Detonation velocities D measured at nominal composition and density ρ, under ambient conditions in large charges. (Continued)

Explosive	Density, ρ [g/cm^3 (Mg/m^3)]	Detonation velocity, D [mm/μsec (km/s)][a]	Ref.
TNM	1.6	6.4 [15-20°C (288-298 K)]	24
TNT	0.95	4.85	3
	1.47	6.48	3
	1.59	6.95	8
	1.6	6.9	1
(pressed)	1.64	6.93	18
(cast)	1.61	6.73	5
(cast at 291 K)	1.62	6.97	25
(cast at 77.4 K)	1.70	6.99	25
(cast at 20.4 K)	1.71	7.00	25
(liquid at 373 K)		∿6.52 in 70-mm-diam x 510-mm-long Pyrex tube	26
(powder)	1.00	4.65	23
XTX-8003	∿1.53	7.30 (in 2-mm-diam channel)	27
XTX-8004	∿1.55	7.22 (in 2-mm-diam channel)	27

a One mm/μsec = 1 km/s.

8.1.1. Equations

To calculate detonation velocities at conditions other than those specified in Table 8-1, the equations in Table 8-2 were developed to take into account composition and density of the explosive, the charge diameter, and the temperature.

Table 8-2. Detonation velocity equations.

Explosive	Equation[a]		Condition	Ref.
AP	$D = 1.146 + 2.576\rho$	$(1.146 + (2.576 \times 10^{3}\rho))$	$0.55 < \rho < 1.0$	33
Baratol	$D = 4.96 - (0.454/R)$	$(4.96 - [(4.54 \times 10^{-3})/R])$	27% TNT, $\rho \sim 2.60$, $2.5 < R < 10$	35
Boracitol	$D = 5.15 - (6.25/R)$	$(5.15 - [(62.5 \times 10^{-3})R])$	$R > 5$ (0.05)	35
BTF	$D = 4.265 + 2.27\rho$	$(4.265 + (2.27 \times 10^{-3}\rho))$	--	30
Comp B, Grade A	$D = 7.99 - [75.6 \times 10^{-3})/R]$ $\Delta D/\Delta T = -0.5 \times 10^{-3}$	$(7.99 - [(0.756 \times 10^{-3})/R])$	$\rho = 1.715$	35
Cyclotol 75/25	$D = 8.298 - [(57.7 \times 10^{-3})/R]$	$(8.298 - [(0.577 \times 10^{-3})/R])$	77% RDX, $\rho = 1.755$	35
DATB	$D = 7.52 - [52.76 \times 10^{-3})/R]$ $D = 2.495 + 2.834\rho$	$(7.52 - [(0.528 \times 10^{-3})/R])$ $(2.495 + (2.834 \times 10^{-3}\rho))$	$\rho = 1.788$ --	
HBX-1	$D_\infty = -0.063 + 4.305\rho$	$(-0.063 + (4.305 \times 10^{-3}\rho))$	--	10
HNAB	$D = 18.579\rho - 5.233\rho^2 - 9.033$	--	$1.40 < \rho < 1.65$	30
LX-01-0	$\Delta D/\Delta T = -3.8 \times 10^{-3}$	--	--	
LX-02	$D = 7.44 - [(4.31 \times 10^{-3})/R]$	$(7.44 - [(43.1 \times 10^{-6})/R])$	Brass confinement; varies with confinement.	
LX-04-1	$D = 1.733 + 3.62\rho$ $D_\infty = 8.46 - [(24.015 \times 10^{-3})/R]$ $\Delta D/\Delta T = -1.55 \times 10^{-3}$ $\Delta D/\Delta W = -38 \times 10^{-3}$	$(1.733 + (3.62 \times 10^{-3}\rho))$ $(8.46 - [(0.24 \times 10^{-3})/R])$ -- --	-- $\rho = 1.86$ -54 to 74°C (219-347 K) (W = wt% Viton)	
LX-07	$\Delta D/\Delta T = -1.55 \times 10^{-3}$ $\Delta D/\Delta W = -35 \times 10^{-3}$	-- --	-54 to 74°C (219-347 K) (W = wt% HMX)	

Table 8-2. Detonation velocity equations. (Continued)

Explosive	Equation[a]		Condition	Ref.
LX-08	$\Delta D/\Delta T = -3.56 \times 10^{-3}$	--	-36 to 23°C (237-296 K)	
LX-09	$\Delta D/\Delta T = -3.31 \times 10^{-3}$	--	-54 to 74°C (219-347 K)	37
LX-13 (See XTX-8003)				
NM	$\Delta D/\Delta T = -3.7 \times 10^{-3}$	--	-20 to 70°C (253-343 K)	38
	$D = 6.268 - [(4.23 \times 10^{-3})(T - T_0)]$	--	--	39
	$\Delta D/\Delta P = 0.197 \times 10^{-3}$ mm/μs-atm	(19.96 km/s-Pa)	4°C (277 K), infinite diam	
NQ	$D = 1.44 + 4.015\rho$	$(1.44 + (4.015 \times 10^{-3}\rho))$	$0.4 \leq \rho \leq 1.63$	36
Octol 75/25	$D = 8.48 - [(64.97 \times 10^{-3})/R]$	$(8.48 - [(0.65 \times 10^{-3})/R])$	77% HMX, $\rho = 1.814$	35
PBX-9010	$D = 2.843 + 3.1\rho$	$(2.843 + (3.1 \times 10^{-3}\rho))$	--	
	$D = 8.371 - [(10.16 \times 10^{-3})/R]$	$(8.371 - [(0.102 \times 10^{-3})/R])$	$\rho = 1.781$	30
PBX-9205	$D = 2.41 + 3.44\rho$	$(2.41 + (3.44 \times 10^{-3}\rho))$	--	
	$D = 4.995 + (36.54 \times 10^{-3}V)$	--	V = vol% RDX; ρ = 97.5% TMD	
PBX-9404	$D = 8.8 - [(24.12 \times 10^{-3})/R]$	$(8.8 - [(0.24 \times 10^{-3})/R)]$	--	
	$D = 2.176 + 3.6\rho$	$(2.176 + (3.6 \times 10^{-3}\rho))$	--	
	$\Delta D/\Delta T = -1.165 \times 10^{-3}$	--	-54 to 74°C (219-347 K)	
Pentolite 50/50	$\Delta D/\Delta T = -0.4 \times 10^{-3}$	-54 to 74°C (219-347 K)	--	
PETN	$D = 2.14 + 2.84\rho$	$(2.14 + (2.84 \times 10^{-3}\rho))$	$\rho < 0.37$	40
	$D = 3.19 + 3.7(\rho - 0.37)$	--	$0.37 < \rho < 1.65$	40
	$D = 7.92 + 3.05(\rho - 1.65)$	--	$\rho > 1.65$	40

Table 8-2. Detonation velocity equations. (Continued)

Explosive	Equation[a]		Condition	Ref.
Picric acid	$D = 5.255 + 3.045(\rho - 1.00)$	--	--	41
RDX	$D = 2.56 + 3.47\rho$	$(2.56 + (3.47 \times 10^{-3}\rho))$	$\rho > 1.0$	42
TATB	$D = 0.343 + 3.94\rho$	$(0.343 + (3.94 \times 10^{-3}\rho))$	$\rho > 1.2$	35
	$D = 7.79 - [(16.8 \times 10^{-3})/R]$	$(7.79 - [(0.168 \times 10^{-3})/R])$	$\rho = 1.876$	
TNT	$D_\infty = 1.873 + 3.187\rho$	$(1.873 + (3.187 \times 10^{-3}\rho))$	$0.9 < \rho < 1.534$	43
	$D_\infty = 6.763 + 3.187(\rho - 1.534) - 25.1(\rho - 1.534)^2 + 115.1(\rho - 1.534)^3$	--	$1.534 < \rho < 1.636$	43
	$D_\infty = 1.67 + 3.342\rho$	$(1.67 + (3.34 \times 10^{-3}\rho)$	--	48
XTX-8003	$D = 7.26 - [(3.02 \times 10^{-3})/R]$	$(7.26 - [(30.2 \times 10^{-6})/R])$	$\rho \approx 1.53$	37
	$D = 3.68 + (44.8 \times 10^{-3}W)$	--	(W = wt% PETN)	
	$\Delta D/\Delta T = -2.34 \times 10^{-3}$	--	-54 to 74°C (219-347 K)	

[a] Symbols and units are: D = detonation velocity in mm/μsec (km/s), ρ = density in g/cm^3 (Mg/m^3), R = charge radius in cm (m), W = composition in wt%, V = composition in vol%, T = temperature in °C (K). Values or equations in parentheses are in SI units.

8.1.2. Estimation

Method a. One method for estimating the detonation velocity and pressure of an organic C-H-N-O explosive from its chemical structure was devised by Kamlet and Jacobs of the U.S. Naval Surface Weapons Center, White Oak Laboratory.[28] Detonation pressures (P) in kbars and detonation velocities (D) in km/s of C-H-N-O explosives at initial densities above 1.0 g/cm^3 can be calculated by means of the simple empirical equations

$$P = K\rho_0^2\phi ,$$

$$D = A\phi^{1/2}(1 + B\rho_0) ,$$

$$\phi = NM^{1/2}Q^{1/2} ,$$

where

- K = 15.58,
- ρ_0 = initial density of HE [g/cm^3 (Mg/m^3)],
- A = 1.01,
- B = 1.30,
- N = moles of gaseous detonation products per gram of HE (mol gas/g HE),
- M = average molecular weight of detonation product gas (g gas/mol gas),
- Q = chemical energy of the detonation reaction (cal/g).

Values of N, M, and Q can be estimated from the H_2O-CO_2 decomposition assumption. The other input parameters are the elemental composition, the ΔH_f in kcal/mol, and the loading density of the HE.

$$C_aH_bN_cO_d \longrightarrow \frac{c}{2} N + \frac{b}{2} H_2O + \left(\frac{d}{2} - \frac{b}{4}\right) CO_2 + \left(a - \frac{d}{2} + \frac{b}{4}\right) C .$$

Then

$$N = \frac{2c + 2d + b}{48a + 4b + 56c + 64d} ,$$

$$M = \frac{56c + 88d - 8b}{2c + 2d + b} ,$$

$$Q = -\Delta H_0 = \frac{\Delta H_f(\text{detonation products}) - \Delta H_f(\text{HE})}{\text{formula weight}}$$

$$= \frac{28.9b + 47.0\left(d - \frac{b}{2}\right) + \Delta H_f(\text{HE})}{12a + b + 14c + 16d} .$$

Method b. Another simple empirical equation was demonstrated by Urizar at LANL in the late 1940s and gives good agreement with measured detonation velocities of mixtures. The detonation velocity of a mixture or formulation can be estimated or predicted as the sum of the detonation or shock velocities of the components weighted by their individual volume fractions. Table 8-3 gives values of characteristic velocities D_i for use in the equation:

$$D = \sum (V_i D_i) ,$$

where D is the detonation velocity of the mixture of infinite diameter, V is the volume fraction, and subscript i refers to each of the i components including void space.[29,30]

Method c. Russian researchers have also developed generalized, simple relationships to estimate detonation velocities of explosives, taking into account the state of the detonation products. Borzykh and Kondrikov[31] developed a generalized relationship for D vs ρ from the many experimental results available. Their formula for secondary HEs is:

$D = 2.395 + 3.589\ \rho$, where ρ is the charge density.

A comparable generalized relationship for the case where the detonation products are completely gaseous is given by Pepekin and Lebedev[32] as:

$$D = 4.2 + 2.0\ \psi\rho ,$$

where ψ is $nQ^{1/2}$, n is mol of gaseous detonation products per gram of HE, Q is the heat of explosion in kcal/g, and ρ is the charge density in g/cm^3.

Table 8-3. Characteristic velocities D_i.[29,30]

Material	Density, ρ [g/cm^3 (Mg/m^3)]	Characteristic velocity, D_i [mm/μsec (km/s)]
Polymers and plasticizers		
Adiprene L	1.15	5.69
AFNOL	1.48	6.35
Beeswax	0.92	6.50
BDNPA-F (50/50 wt% eutectic)	1.39	6.31
BDNPF	1.42	6.50
CEF	1.45	5.15
DNPA	1.47	6.10
EDNP	1.28	6.30
Estane 5740-X2	1.2	5.52
Exon-400 XR61	1.7	5.47
Exon-454 (85/15 wt% PVC/PVA)	1.35	4.90
FEFO (as constituent to ~35%)	1.60	7.20
Fluoronitroso rubber	1.92	6.09
Halowax 1014	1.78	4.22
Kel-F wax		5.62
Kel-F elastomer	1.85	5.38
Kel-F 800/827	2.00	5.83[a]
Kel-F 800	2.02	5.50
Neoprene CNA	1.23	5.02
NC	1.58	6.70
Paracril BJ (Buna-N nitrile rubber)	0.97	5.39
Polyethylene	0.93	5.55
Polystyrene	1.05	5.28
Saran F-242		5.55
Silastic 160		5.72
Sylgard 182	1.05	5.10
Teflon	2.15	5.33
Viton A	1.82	5.39

Table 8-3. Characteristic velocities D_i.[29,30] (Continued)

Material	Density, ρ [g/cm^3 (Mg/m^3)]	Characteristic velocity, D_i [mm/μsec (km/s)]
	Inorganic additives	
Air or void		1.5
Al	2.70	6.85
$Ba(NO_3)_2$	3.24	3.80
$KClO_4$	2.52	5.47
$LiClO_4$	2.43	6.32
LiF	2.64	6.07
Mg	1.74	7.2
Mg/Al alloy (61.5/38.5 wt%)	2.02	6.9
NH_4ClO_4	1.95	6.25
SiO_2 (Cab-O-Sil)	2.21	4.0
	Pure explosives at TMD	
DATB	1.84	7.52
FEFO (invalid when <35% present)	1.61	7.50
HMX	1.90	9.15
NQ	1.81	8.74
PETN	1.78	8.59
RDX	1.81	8.80
TATB	1.94	8.00
TNT	1.654	6.97

a One shot only.

Method d. Rothstein and Peterson[94] found that a linear relationship exists for ideal explosives between the detonation velocity at TMD and a factor F, which is dependent only on the chemical composition and structure of the HE. On the basis of experimental data, the following relationship is applicable to C-H-N-O-F explosives. Detonation velocities can be predicted quickly and easily for newly developed compositions.

$$D' = \frac{F - 0.26}{0.55} = D_0 + 3.0\ (\rho_{TM} - \rho_0) \quad ,$$

where

D' = estimated detonation velocity at TMD ρ_{TM},

D_0 = experimental detonation velocity at ρ_0, and

$$F = \left[100\ \frac{n(O) + n(N) + n(F) - \dfrac{n(H) - n(HF)}{2n(O)} + \dfrac{A}{3} - \dfrac{n(B/F)}{1.75} - \dfrac{n(C)}{2.5} - \dfrac{n(D)}{4} - \dfrac{n(E)}{5}}{MW} \right] - n(G)$$

where

G = 0.4 for each liquid explosive component and 0 for solid explosives,

A = 1 for aromatic compounds; otherwise A = 0,

and where, for 1 mol of the composition,

n(O) = number of oxygen atoms,

n(N) = number of nitrogen atoms,

n(H) = number of hydrogen atoms,

n(F) = number of fluorine atoms,

n(HF) = number of hydrogen fluoride molecules that can possibly form from available hydrogen,

n(B/F) = number of oxygen atoms in excess of those available to form CO_2 and H_2O and/or the number of fluorine atoms in excess of those available to form HF,

n(C) = number of oxygen atoms doubly bonded directly to carbon (as in a ketone or ester),

n(D) = number of oxygen atoms singly bonded directly to carbon (as in >C-O-R and where R can be -H, $-NH_4$, -C, etc.),

n(E) = number of nitrato groups existing either as a nitrate ester or as a nitric acid salt such as hydrazine mononitrate.

The relation $[n(H) - n(HF)]/2n(O)$ is 0 if $n(O) = 0$ or if $n(HF) \geq n(H)$.

8.2. CHAPMAN-JOUGUET DETONATION PRESSURE

In idealized detonation theory, a detonation front consists of several regions:

(1) The leading surface is a chemically unreactive shock front with a discontinuous high pressure.

(2) The reaction zone, which follows the shock front, is where chemical reactions take place that release the bulk of the detonation energy; its thickness is estimated to be about 10^{-1} mm for some pure explosives, but may vary by several powers of 10 depending on the HE.

(3) The Chapman-Jouguet (C-J) plane is the surface at the rear of the reaction zone.

(4) The Taylor wave, a rarefaction wave, is the expansion flow following the C-J state.

Complete thermodynamic equilibrium is assumed to exist at the C-J plane, and the detonation products are said to be at the C-J state. Detonation pressure normally refers to the pressure in the C-J state, which is somewhat lower than the pressure at the shock front.

Experimentally, C-J pressures (Table 8-4) are measured by various indirect hydrodynamic methods. These measurements may span a range of 10-20%, and their exact interpretation is uncertain. The calculated C-J pressures (Table 8-4) are obtained with the TIGER hydrodynamic-thermodynamic computer code, which combines the Rankine-Hugoniot conservation equations, the C-J condition, the density ρ and enthalpy of formation ΔH_f of the explosive, the laws of chemical thermodynamic equilibrium, and the Brinkley-Kistiakowsky-Wilson (BKW) equation of state for the gaseous products. The code parameters are normalized with measured detonation velocities and C-J pressures of several explosives.

Table 8-4. Detonation pressures, P_{CJ}.

Explosive	Density, ρ [g/cm³ (Mg/m³)]	P_{CJ} [kbar (10^{-1} GPa)][a] Measured	P_{CJ} [kbar (10^{-1} GPa)][a] Calculated	Ref.
AP	1.95	-	187	44
Baratol	2.61	140	-	
BTF	1.859	360	309	45
Comp B, Grade A	1.717	295[b]	-	
Comp B-3	1.715	287	-	
Comp C-4	1.59	-	257	
Cyclotol 77/23	1.752	316	-	
DATB	1.78	259	250	
FEFO	1.59	250	232	45
HBX-1	1.712	220.4	-	10
HMX	1.89	390	394	45
HNAB	1.60	205	-	11
HNS	1.60	-	200	46
LX-01	1.31	156	177	
LX-04	1.865	350	330	
LX-07-2	1.865	-	346	
LX-09-0	1.837	377	373	
LX-10	1.860	375	360	
LX-11	1.87	-	310	
LX-13 (See XTX-8003)				
LX-14	1.833	370	-	
LX-15	1.58	-	188	16
LX-17-0	1.900	300		92
MEN-II	1.017	-	113	
NC (12.0% N)	1.58	-	200	
NC (13.35% N)	1.58	-	210	
NG	1.59	253	251	
NM	1.135	125	144	45
Octol 77.6/22.4	1.821	342	-	

Table 8-4. Detonation pressures, P_{CJ}. (Continued)

Explosive	Density, ρ [g/cm^3 (Mg/m^3)]	P_{CJ} [kbar (10^{-1} GPa)][a]		Ref.
		Measured	Calculated	
PBX-9007	1.60	265	-	
PBX-9010	1.783	328±5	-	
PBX-9011	1.767	324±5	-	
PBX-9205	1.69	-	288	
PBX-9404	1.840	375	354	
PBX-9407	1.60	287	300	
Pentolite 50/50	1.70	-	255	22
PETN	1.77	335	332	45
	1.67	300	280	
	0.99	87	100	
Picric acid	1.76	-	265	35
	1.00	-	88	35
RDX	1.767	338	348	
TACOT	1.61	-	181	
TATB	1.88	-	291	
Tetryl	1.71	-	260	
TNM	1.65	-	144	
TNT	1.630	210	223	45
XTX-8003	1.546	170	210	

[a] One GPa = 10 kbar.
[b] Pressure can be corrected for small changes in % RDX and density by the formula $P = 295 + 1.57\,(\%RDX - 64) + 678.5\,[(\rho_0 - 1.717)/\rho_0]$.

8.2.1 Reaction zone

Defining the thickness of the reaction zone is open to some question because the zone cannot be measured directly. The thickness (also called length or width) is generally inferred from hydrodynamic experiments, but the techniques used are frequently questionable, and the equations are based on or inferred from measurements of detonation velocity vs charge diameter.

Eyring[47] determined that the reaction zone is about 1 mm long for typical HEs. He resoned that reaction zones for primary HEs would be smaller than 0.1 mm and would therefore be difficult--if not impossible--to determine.

The values given in Table 8-5 are approximations. Experimental techniques and results should be verified with the original author (see references). Figure 8-1 compares the derived reaction zone "length" for TNT as a function of loading density for confined and unconfined charges, as reported by Urizar, James, and Smith[43] and by Stesik and Akimova[48].

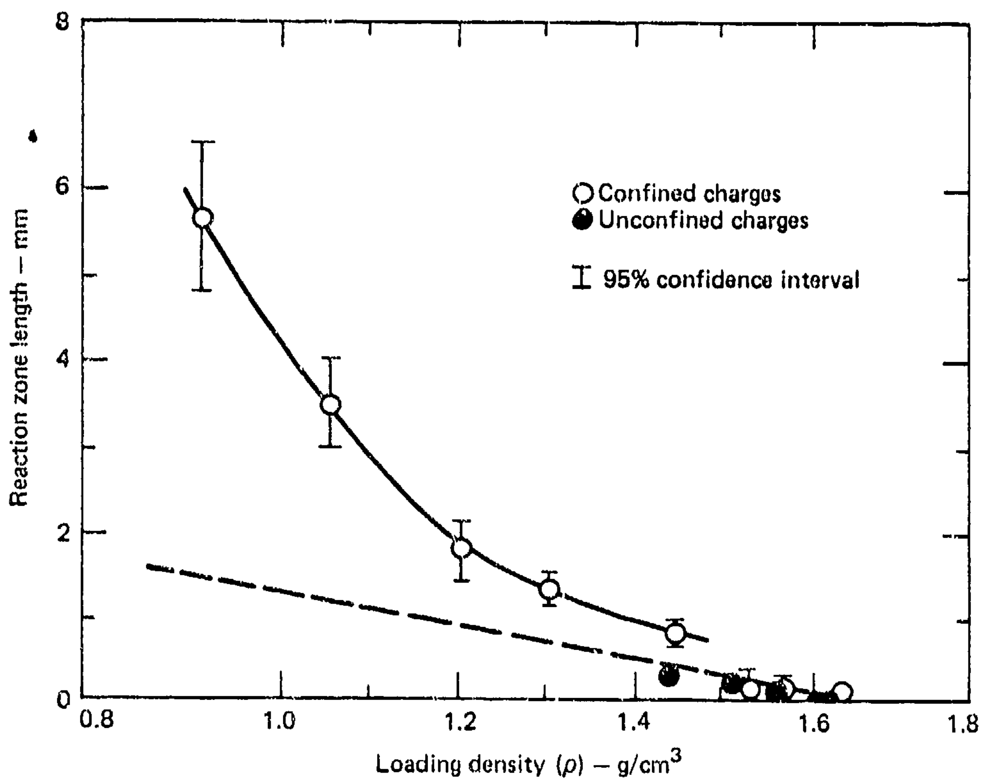


Fig. 8-1. The detonation reaction zone length for TNT as a function of loading density.[43,48]

Table 8-5. Reaction zone length.

Explosive	Density, ρ [g/cm^3 (Mg/m^3)]	Approximate length (mm)	Conditions Charge diameter (mm)	Ref.
Amatol 80/20	1.67	4		47
AP (10μ)	1.00	6.3	203 mm long	34
	1.10	6.7	203 mm long	34
	1.20	8.0	203 mm long	34
	1.26	10.0	203 mm long	34
Comp B	1.67	0.13 (Al plate)	140x140x76	49
HBX-1	1.60	0.19		10
NG		0.21		47
NM	1.128	0.3-0.6	0.25-mm thick-walled paper tube	50
	1.128	0.03	Pyrex cylinder	39
		0.08 at -5°C	25.4-mm-OD brass tube	51
		0.27 at 33°C	25.4-mm-OD brass tube	51
NM/acetone 75/25		0.21		52
	1.05	1.60	80	53
	1.05	0.80	55	53
PBX-9502	1.895	3.3	200	20
Picric acid		2.2	glass cylinder	47
RDX		0.826		47
(microporous)	1.30	1.82	cylinder	54
(single crystal)	1.80	2.90	DxL = 1.23	54
TATB		0.5-0.65	cylinder	91
TNT		0.36	steel cylinder	47
	1.00	0.32 (Mg plate)	40, 90 mm long	55
	1.55	0.18 (Al plate)	40, 90 mm long	55
		0.13 (Cu plate)	40, 90 mm long	55
		0.21 (Mg plate)	40, 90 mm long	55
	1.59	0.70	60 mm long	53
(pressed)	1.63	0.3	90 mm long	56
(cast)	1.615	0.42 at 291 K		25
	1.70	0.55 at 77.4 K	8-56 in. 0.2-mm	25
	1.71	0.62 at 20.4 K	paper cylinder	25
(liquid)		0.9 at 100°C	glass cylinder	26
		1.1 at 100°C	Dural cylinder	26
TNT/RDX 50/50	1.67	0.12	90	56

8.3. CYLINDER-TEST MEASUREMENTS OF EXPLOSIVE ENERGY

The cylinder test gives a measure of the hydrodynamic performance of an explosive. The test geometry is based on a constant volume of HE. The test system consists of an explosive charge 1 in. in diameter and 12 in. long (25 by 310 mm) in a tightly fitting copper tube with a wall 0.1022 in. (2.6 mm) thick. The charge is initiated at one end. The radial motion of the cylinder wall is measured at about 8 in. (200 mm) from the initiated end using a streak camera. The camera records are reduced to provide detailed radius-time information.

The kinetic energy imparted to a copper wall in a given geometry leads to a simple way of expressing the performance of the explosive. In this range of the mass ratio of explosive to metal, two extreme geometric arrangements are considered for transfer of explosive energy to adjacent metal: 1) detonation that is normal or head-on to the metal and (2) detonation that is tangential or sideways to the metal. The effective explosive energy frequently differs for the two cases, even on a relative basis, because of the effects of the equations of state of the detonation products.

The cylinder test provides a measure of the relative effective explosive energy for detonations in both head-on and tangential geometries. The radial-wall velocity at 5-6 mm wall displacement, expressed as volume ratio $V = V/V_0 \approx 2$, indicates the explosive energy of head-on detonation. The radial-wall velocity at 19 mm displacement, where $V/V_0 \approx 7$, indicates energy in tangential geometry.

Table 8-6 lists the specific wall kinetic energies at 6 and 19 mm wall displacement; terminal wall velocities at breakup are about 7-10% higher. About 50% of the detonation energy is transferred to the cylinder wall.

Table 8-6. Cylinder tests.

Explosive	Density, ρ [g/cm^3 (Mg/m^3)]	E_{cyl} $\frac{(mm/\mu s)^2}{2}$ (MJ/kg) Head on (6 mm)	Tangential (19 mm)	Ref.
BTF	1.859	1.305	1.680	30
Comp A-3	1.59		~1.20	30
Comp B, Grade A	1.717	1.035	1.330	30
Comp B-3	1.728	1.01	1.322	30
Comp C-4	1.601	0.962	1.258	30
Cyclotol 77/23	1.754	1.140	1.445	30
H-6	1.76	0.769	1.066	30
HMX	1.894	1.410	1.745	30
LX-04-1	1.865	1.170	1.470	30
LX-07-1	1.857	1.250	1.575	30
LX-09-0	1.836	1.320	1.675	30
LX-10	1.862	1.315	1.670	30
LX-11	1.876	1.105	1.360	30
LX-13 (See XTX-8003)				
LX-14	1.835	0.985	1.614	30
LX-15	1.58	0.700	0.929	30
LX-17	1.908	0.87	1.07	30
NM	1.14[a]	0.560	0.745	30
Octol 78/22	1.813	1.215	1.535	30
PBX-9010	1.788	1.160	1.470	30
PBX-9011	1.777	1.120	1.415	30
PBX-9404	1.843	1.295	1.620	30
PBX-9501	1.834	1.177	1.577	21
PBX-9502	1.889	0.845	1.037	96
Pentolite 50/50	1.696	0.960	1.260	30
PETN	1.765	1.255	1.575	30
RDX	1.80		~1.60	30
TATB	1.854	0.874	1.079	30
TNT	1.630	0.735	0.975	30
XTX-8003	1.554	0.710	0.950	30

[a]Density at 11-15°C (284-288 K).

8.3.1. Equation of state

The Jones-Wilkins-Lee (JWL) equation of state has been used to describe accurately the pressure-volume-energy behavior of the detonation products of explosives in applications involving metal acceleration. All values are valid only for large charges.[57] The equation for pressure P is:

$$P = A\left(1 - \frac{\omega}{R_1 V}\right)e^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right)e^{-R_2 V} + \frac{\omega E}{V} ,$$

and that for P_s, pressure as a function of volume at constant entropy (i.e., the isentrope), is:

$$P_s = Ae^{-R_1 V} + Be^{-R_2 V} + CV^{-(\omega+1)} ,$$

where

- A, B, and C = linear coefficients in Mbar (GPa),
- R_1, R_2, and ω = nonlinear coefficients,
- $V = v/v_0$ = the volume of detonation products/volume of undetonated HE,
- P and P_s = pressure in Mbar (GPa),
- E = the detonation energy per unit volume in $(\text{Mbar-cm}^3)/\text{cm}^3$ $[(\text{GPa-m}^3)/\text{m}^3]$.

Table 8-7 lists equation-of-state parameters. For some explosives, the coefficients were determined by rigorously comparing values calculated using the equation with experimental C-J conditions, calorimetric data, and expansion behavior (usually cylinder-test data). These explosives are listed in Table 8-7 without additional notation. If only limited data were available, the coefficients were estimated; for these HEs, the estimated parameters are listed as noted. The best estimates are those for which cylinder-test data were available. In many instances, P_{CJ} was estimated by assuming that $2.7 < \Gamma < 2.8$, where Γ is the adiabatic coefficient of expansion; $\Gamma = (\partial \ln P/\partial \ln V)_s$ at the Chapman-Jouguet plane. If the data were extremely limited, estimates were made using TIGER code calculations.

Table 8-7. Equation-of-state parameters.[a]

Explosive	C-J parameters: ρ_0 [g/cm^3 (Mg/m^3)]	C-J parameters: P [Mbar (100 GPa)]	C-J parameters: D [cm/μsec (10^{-1} km/s)]	C-J parameters: E_0 [Mbar-cm^3/cm^3 (100 GPa-m^3/m^3)]	C-J parameters: Γ	Equation-of-state parameters: A [Mbar (100 GPa)]	Equation-of-state parameters: B [Mbar (100 GPa)]	Equation-of-state parameters: C [Mbar (100 GPa)]	R_1	R_2	ω	Ref.
BTF[a]	1.859	0.360[b]	0.848	0.1150	2.717	8.407	0.14960	0.01368	4.60	1.20	0.30	58
Comp A-3[a]	1.65	0.300	0.83	0.089	2.79	6.113	0.1065	0.0108	4.4	1.2	0.32	59
Comp B, Grade A	1.717	0.295	0.798	0.0850	2.706	5.242	0.07678	0.01082	4.20	1.10	0.34	58
Comp C-4	1.601	0.280	0.8193	0.090	2.838	6.0977	0.1295	0.01043	4.5	1.4	0.25	60
Cyclotol 77/23	1.754	0.320	0.825	0.0920[b]	2.731	6.034	0.09924	0.01075	4.30	1.10	0.35	58
DIPAM[a]	1.550	0.180[b]	0.670	0.0620[b]	2.842	4.254	0.08007	0.01175	4.70	1.30	0.39	58
EL-506A[a]	1.480	0.205[b]	0.720	0.0700[b]	2.752	3.738	0.03647	0.01138	4.20	1.10	0.30	58
EL-506C[a]	1.480	0.195[b]	0.700	0.0620[b]	2.719	3.490	0.04524	0.00854	4.10	1.20	0.30	58
Explosive D[a]	1.42	0.160	0.65	0.054	2.75	3.007	0.0394	0.0100	4.3	1.2	0.35	59
FEFO[a]	1.590	0.250	0.750	0.0800	2.578	3.824	0.06635	0.01444	4.10	1.20	0.38	45
H-6[c]	1.76	0.240	0.747	0.103	3.092	7.5807	0.08513	0.01143	4.9	1.1	0.20	70
HMX	1.891	0.420[b]	0.911	0.1050	2.740	7.783	0.07071	0.00643	4.20	1.00	0.30	58
HNS	1.00	0.075	0.510	0.041	2.468	1.627	0.1082	0.006580	5.4	1.8	0.25	46
HNS	1.40	0.145	0.634	0.060	2.881	3.665	0.06750	0.01163	4.8	1.40	0.32	46
HNS	1.65	0.215	0.703	0.0745	2.804	4.631	0.08873	0.01349	4.55	1.35	0.35	46
LX-01[a]	1.230	0.155	0.684	0.0610[b]	2.711	3.110	0.04761	0.01039	4.50	1.00	0.35	58
LX-04-1	1.865	0.340	0.847	0.0950	2.935	8.364	0.1298	0.01471	4.62	1.25	0.42	62
LX-07	1.865	0.355	0.864	0.1000	2.922	8.710	0.1390	0.00891	4.60	1.15	0.30	62
LX-09-1	1.84	0.375	0.884	0.105	2.834	8.481	0.1710	0.01308	4.58	1.25	0.40	62
LX-10-1	1.865	0.375	0.882	0.104	2.868	8.807	0.1836	0.01296	4.62	1.32	0.38	62
LX-11	1.875	0.330	0.832	0.0900[b]	2.868	7.791	0.10668	0.00885	4.50	1.15	0.30	61
LX-13 (See XTX-8003)												
LX-14-0	1.835	0.370	0.88	0.102	2.841	8.261	0.1724	0.01296	4.55	1.32	0.38	62
LX-17-0	1.900	0.300	0.7600	0.0690	2.658	4.46	0.01339	0.01306	3.85	1.03	0.46	92
NM	1.128	0.125	0.628	0.0510	2.559	2.092	0.05689	0.00770	4.40	1.20	0.30	58
Octol 78/22	1.821	0.342	0.848	0.0960[b]	2.830	7.486	0.13380	0.01167	4.50	1.20	0.38	58

Table 8-7. Equation-of-state parameters.[a] (Continued)

Explosive	C-J parameters					Equation-of-state parameters						Ref.
	ρ_0	P	D	E_0	Γ	A	B	C				
	[g/cm^3 (Mg/m^3)]	[Mbar (100 GPa)]	[cm/μsec (10^{-1} km/s)]	[Mbar-cm^3/cm^3 (100 GPa-m^3/m^3)]		[Mbar (100 GPa)]			R_1	R_2	ω	
PBX-9010	1.787	0.340	0.839	0.0900	2.700	5.814	0.06801	0.00234	4.10	1.00	0.35	58
PBX-9011	1.777	0.340	0.850	0.0890[b]	2.776	6.347	0.07998	0.00727	4.20	1.00	0.30	58
PBX-9404-3	1.840	0.370	0.880	0.1020	2.851	8.524	0.1802	0.01207	4.60	1.30	0.38	62
PBX-9407	1.600	0.265[b]	0.791	0.0860[b]	2.513	5.73187	0.146390	0.01200	4.60	1.40	0.32	58
PBX-9501	1.840	0.370	0.880	0.1020	2.851	8.524	0.1802	0.01207	4.55	1.30	0.38	61
PBX-9502	1.895	0.302	0.771	0.0707	2.648	4.603	0.09[illegible]44	0.01343	4.0	1.70	0.48	97
Pentolite 50/50	1.70	0.255	0.753	0.081	2.73	5.4094	0.093726	0.01033	4.5	1.1	0.35	22
PETN[a]	0.880	0.062	0.517	0.0502[b]	2.068	3.486	0.11288	0.00941	7.00	2.00	0.24	58
PETN	1.260	0.140	0.654	0.0719[b]	2.831	5.731	0.20160	0.01267	6.00	1.80	0.28	58
	1.500	0.220	0.745	0.0856[b]	2.788	6.253	0.23290	0.01152	5.25	1.60	0.28	58
	1.770	0.335	0.830	0.1010	2.640	6.170	0.16926	0.00699	4.40	1.20	0.25	58
Tetryl	1.730	0.285	0.791	0.0820	2.798	5.868	0.10671	0.00774	4.40	1.20	0.28	58
TNT	1.630	0.210	0.693	0.07	2.727	3.712	0.03231	0.01045	4.15	0.95	0.30	58

[a] Cylinder data are not available.
[b] Estimated quantities.
[c] This is a composite HE with non-ideal behavior.

8.3.2. Detonation energy

Detonation energies[63] (as measured by metal acceleration in the cylinder test) of formulations containing mostly HMX can be correlated with the volume fraction of additives by a simple linear relationship:

$$E = E_{HMX}\left(1 - \sum S_i V_i\right), \tag{8-1}$$

where

E = detonation energy per unit volume of a formulation at its loaded density.

E_{HMX} = detonation energy per unit volume of pure HMX at its TMD of 1.90 g/cm^3 (Mg/m^3). The reference value is (wall velocity)^2 at 19 mm displacement in the cylinder test, corrected to TMD. The corrected wall velocity is 1.872 mm/μsec (km/s).

S_i = characteristic energy decrement for each diluent.

V_i = volume fraction of each additive.

The energy decrement for a fixed combination of two or more ingredients is readily computed as:

$$S_b = \frac{\sum S_i V_i}{\sum V_i} \quad \text{and} \quad V_b = \sum V_i\ , \tag{8-2}$$

where the subscript b denotes the fixed combination. The quantity $S_b V_b$ for the combination becomes one of the terms in Eq. (8-1). An $S_i V_i$ term for air or void takes account of porosity in the actual explosive. A convenient form of Eq. (8-1) gives relative energy as a percentage of HMX energy, $E_{Rel\%}$, and as a function of the volume percent, $V_{i\%}$, of additives:

$$E_{Rel\%} = \frac{100E}{E_{HMX}} = 100 - \sum S_i V_{i\%}\ . \tag{8-3}$$

The characteristic energy decrement S_i can be recognized as a percent energy degradation from pure HMX for each volume percent of the additive. The S_i values for a number of additives are given in Table 8-8. Neither the applicable range of composition nor the exact linearity of Eq. (8-1) has been tested, but all formulations contained at least 70 wt% HMX.

Table 8-8. Characteristic energy decrement S_i from pure HMX for additives to HMX.

Additive	$\frac{S_i}{(E_{Rel\%}/V_i)}$	Additive	$\frac{S_i}{(E_{Rel\%}/V_i)}$
AFNOL	0.75	FEFO	0.3
Air	1.3	Graphite	1.3
BEAF	0.75	HNS[a]	0.5
BDNPA	0.75	Kel-F	1.0
BDNPA-F 50/50	0.75	NC	0.75
BDNPF	0.75	NG[a]	0.3
CAB	1.3	Nitrosorubber	0.75
CEF	1.3	NONA[a]	0.5
DATB[a]	0.5	Polyethylene	1.3
DFTNB	0.25	Sylgard	1.3
DIPAM[a]	0.5	TACOT[a]	0.5
DNPA	0.75	TATB[a]	0.5
DNPN	0.75	Teflon	1.0
EDNP	0.75	TNT	0.5
Estane	1.3	Viton	1.0
Exon (polyvinyl chloride/		Void	1.3
polyvinyl alcohol 85/15)	1.0	Wax	1.3

[a] Materials were not actually tested; values were estimated with the TIGER code.

R. W. Gurney[64,65] devised a simple model that permits estimation of the velocity of metal driven by a detonating explosive. The method assumes that 1) on detonation, a given explosive liberates a fixed amount of specific energy (E) that is converted to kinetic energy partitioned between the driven metal and the product gases, and 2) the velocity profile in the product gases is linear in material coordinates. For symmetric geometries, an energy balance then indicates that the terminal metal velocity (V_M) is a function of the ratio of the metal mass M to the explosive charge mass C. For asymmetric geometries, a momentum balance must be solved simultaneously. The Gurney characteristic velocity for a given explosive is $\sqrt{2E}$. A solution for the acceleration of flat plates has been worked out as a function of plate displacement by making a further assumption: an ideal gas equation of state describes the behavior of the detonation product gas.

The Gurney velocities for simple geometries are summarized below:

<u>Symmetric sandwich</u>: $V_M = \sqrt{2E}\left(\frac{M}{C} + \frac{1}{3}\right)^{-1/2}$,

<u>Flat plate</u>: $V_M = \sqrt{2E}\left\{1\left[-\left(\frac{X_M}{X_{M_0}}\right)(A + 1) - A\right]^{-B/F}\right\}^{1/2} \Big/ B^{1/2}$,

<u>Sphere</u>: $V_M = \sqrt{2E}\left(\frac{M}{C} + \frac{3}{5}\right)^{-1/2}$,

<u>Cylindrical tube</u>: $V_M = \sqrt{2E}\left(\frac{M}{C} + \frac{1}{2}\right)^{-1/2}$,

where

M/C = $[(OD/ID)^2 - 1)]\ \rho_M/\rho_C$,

X_M = position of product gas/metal interface,

X_{M_0} = initial thickness of explosive, which equals the initial value of X_M,

A = $(2M/C + 1)/(2N/C + 1)$,

N = mass of tamper plate (on explosive surface opposite plate M); N may assume any value,

γ = polytropic exponent of ideal (product) gas,

B = $\frac{N}{C}A^2 + \frac{M}{C} + \frac{1}{3}\left(\frac{1 + A^3}{1 + A}\right)$,

F = $\frac{M}{C}\left[\frac{(A + 1)}{(\gamma - 1)}\right]$.

The efficiency ϵ for converting chemical energy to kinetic energy of plate M may be written as:

$$\epsilon = \frac{MV_M^2/2}{CE} = \frac{M}{C}\left(\frac{V_M}{\sqrt{2E}}\right)^2 .$$

Two other correlations for estimating Gurney velocities are based on Kamlet and Jacob's characteristic value ϕ (see Section 8.1.2.) used to estimate detonation velocities. The equations are:

$\sqrt{2E} = 0.6 + 0.54\sqrt{1.44\phi\rho_0}$, developed by Hardesty and Kennedy.[66]

$\sqrt{2E} = 0.887\ \phi^{0.5}\rho_0^{0.4}$, developed by Kamlet and Finger.[67]

Table 8-9 gives two Gurney constants, one used for warheads in which confining cases rupture at small expansions (prompt) and the other for warheads in which more ductile case materials expand further before rupturing (terminal).

Table 8-9. Gurney values ($\sqrt{2E}$).

Explosive	Density, ρ [g/cm³ (Mg/m³)]	$\sqrt{2E}$ at cylinder expansion[a] prompt (5-7 mm) [mm/μsec (km/s)]	terminal (19-26 mm)	Ref.
Comp A-3	1.61	2.402		68
	1.59		2.63	69
Comp B	1.71		2.70	69
	1.717	2.350	2.756-2.821	68
	1.717		2.71	66
(cast)	1.68	2.402		68
	1.62	2.32		68
(pressed)	1.59	2.335		68
Comp C	1.52	2.176		68
Comp C-3	1.60		2.68	71
Cyclotol 75/25	1.754		2.79	66
(cast)	1.69	2.286		68
(pressed)	1.64	2.362		68
DATB	1.68	1.975		68
Explosive D	1.50	1.942		68
H-6	1.71	2.350		68
(25.4-mm diam)	1.76	2.000	2.433-2.517	70
(50.8-mm diam)	1.76	2.035	2.519-2.636	70
HBX-1	1.70	2.213		68
HBX-3	1.81	1.984		68
HMX	1.89		2.97	66
LX-14			2.80	69
Minol-2	1.68	1.789		68
NM	1.14		2.41	66
NQ	1.44	1.896		68
Octol 75/25	1.81		2.80	69
	1.821		2.83	66

Table 8-9. Gurney values ($\sqrt{2E}$). (Continued)

Explosive	Density, ρ [g/cm^3 (Mg/m^3)]	$\sqrt{2E}$ at cylinder expansion[a] prompt (5-7 mm) [mm/μsec (km/s)]	terminal (19-26 mm)	Ref.
PBX-9011		2.82		69
PBX-9404	1.84		2.90	71
PBX-9502	1.885		2.377	69
Pentolite 50/50				
(cast)	1.64	2.301		68
(pressed)	1.57	2.317		68
PETN	1.76		2.93	66
RDX	1.59	2.451		68
	1.77		2.93	66
TACOT	1.61		2.12	71
Tetryl	1.63	2.274		68
	1.62		2.50	66
TNT	1.630	2.039	2.419-2.505	70
	1.63		2.37	66
(cast)	1.61	2.097		68
(pressed)	1.54	2.103		68

[a] The number in the second decimal place is the last significant figure.

8.5. CRITICAL DIAMETER

Critical diameter, also called failure diameter, is the minimum diameter at which a cylindrical charge of HE sustains a high-order steady-state detonation. This critical diameter (d_c) is affected by changes in confinement, density, particle size, and initial temperature of the sample. The addition of wax to HMX and RDX (i.e., coating the grains) affects the critical diameter only slightly. The failure diameters of various explosives are given in Table 8-10. Critical diameters as a function of temperature are shown in Figs. 8-2 and 8-3 for NG and liquid TNT.[89]

Table 8-10. Critical diameter (d_c).

Explosive	Density, ρ [g/cm³ (Mg/m³)]	Critical diam (d_c) (mm)	Conditions	Ref.
Amatol 80/20 (cast)	-	80	-	47
AN	low-density	≈100	Confined in steel tube.	72
	~0.95	~12.7	Encased in paper tube, poor reproducibility.	3
(pressed)	1.4	no detonation	100-mm-diam charge confined in glass tubing.	73
	1.61	no detonation	36.5-mm-diam charge confined in 11-mm-thick steel tube.	73
AP (particle	0.8-1.0	14		74
size 5μ; sifted	1.1	23 at 20°C	Charge length is 8-10 times the diam.	75
through nylon mesh having	1.1	12 at 200°C	Charge length is 8-10 times the diam.	75
70±10μ openings)	1.2	~28 at 20°C	In Cellophane tube.	75
(poured, 200μ)	1.29	>76.2	203-mm-long charge.	34
(pressed, 10μ)	1.56	76.2	203-mm-long charge.	34
Baratol (cast)	2.619	43.2	Unconfined.	20
Black powder (low-density)		≈100	Confined in steel tube.	72
Comp A-3 (pressed)	1.63	<2.2	-	95

Table 8-10. Critical diameter (d_c). (Continued)

Explosive	Density, ρ [g/cm^3 (Mg/m^3)]	Critical diam (d_c) (mm)	Conditions	Ref.
Comp B 36/63/1 (cast)	1.70	4.28	Unconfined.	20
Comp B-3 (cast)		3.73-4.24	Unconfined.	76
		∿3.18	Encased in Plexiglas tube.	76
		∿2.54	Confined in steel tube.	76
Comp C-4	1.53-1.56	$3.81<d_c<5.08$	Confined.	77
Cyclotol 77/23 (cast)	1.740	6.0	Unconfined.	20
DATB	1.800	5.3	Unconfined.	78
Explosive D	1.65	<25.4	Unconfined.	93
FEFO		<3.43	Confined in 3.18-mm-thick 102-mm-long steel tube.	76
HXB-1 (pressed)	1.72	6.35	Unconfined.	10
(cast)	1.72	>6.35		10
HMX/Wax 90/10	1.10	$6.0<d_c<7.0$	–	79
78/22	1.28	$7.0<d_c<8.0$	–	79
70/30	1.42	$8.0<d_c<9.0$	–	79
Lead azide	3.14	0.4-0.6	–	80
NM	1.128	2.86	Encased in 3.18-mm-thick brass tube.	20
	1.127	<3	Encased in 12.7-mm-diam 6.4-mm-long pellet.	81
	1.127	>11.76	Unconfined at ∿25°C.	81
	1.128	16.2	Encased in 22-mm-ID Pyrex tube at 24.5°C.	39
	1.128	36	Encased in 16.3-mm-ID glass tube at -24°C.	38
	1.128	28	Encased in 16.3-mm-ID glass tube at -8°C.	38
	1.128	20	Encased in 16.3-mm-ID glass tube at 12°C.	38
	1.128	14	Encased in 16.3-mm-ID glass tube at 34°C.	38
	1.128	27	Encased in 0.25-mm-thick-walled paper tube at 18-22°C.	50

Table 8-10. Critical diameter (d_c). (Continued)

Explosive	Density, ρ [g/cm^3 (Mg/m^3)]	Critical diam (d_c) (mm)	Conditions	Ref.
NQ	1.52	$1.27<d_c<1.43$	–	36
Octol 75/25 (cast)	1.814	<6.4	Unconfined.	20
PBX-9404	–	∿1.02	Encased in Plexiglas or steel tubes.	76
	1.846	∿1.18	Unconfined.	20,39
PBX-9501	1.832	<1.52	Unconfined.	20
PBX-9502	1.893	$10<d_c<12$	At −55°C.	82
	1.894	$8<d_c<10$	At 24°C.	82
	1.895	9	Unconfined.	20
PBX-9503	1.897	$4<d_c<6$	–	21
Pentolite 50/50 (cast)	–	6.7	Unconfined.	83
PETN (powder)	0.4-0.7	≥ 0.3	Encased in 0.05-mm-thick cellophane casing.	84
(single crystal)	–	$8.38<d_c<19$	6.4 x 11.1-mm rod.	72
Picric acid	0.9	5.20	–	85
RDX	0.9	5.20	–	85
RDX/TNT 100/0	1.0	3	–	74
90/10	1.0	3.5	–	74
80/20	1.0	3.75	–	74
70/30	1.0	4.25	–	74
50/50	1.0	5.25	–	74
40/60	1.0	5.75	–	74
20/80	1.0	7.0	–	74
10/90	1.0	7.5	–	74
0/100	1.0	7.5	–	74
RDX/Wax 95/5	1.05	$4.0<d_c<5.0$	Encased in cellophane shells with D:L = 1:$\geq$10	79
90/10	1.10	$4.0<d_c<5.0$		79
80/20	1.25	$3.8<d_c<5.0$		79
72/28	1.39	$3.8<d_c<5.0$		79
TACOT	1.45	3	Unconfined.	86
TATB (60 μ)	1.6-1.7	$6.35<d_c<9.53$		87
(20 μ)	1.6-1.7	<6.35		87

Table 8-10. Critical diameter (d_c). (Continued)

Explosive	Density, ρ [g/cm^3 (Mg/m^3)]	Critical diam (d_c) (mm)	Conditions	Ref.
TNT (cast)[a]	1.70	9	Encased in 0.2-mm paper T=77.4 K.	88
	1.71	11	Encased in 0.2-mm paper T=20.4 K.	88
	1.62	15	Encased in 0.2-mm paper T=291 K.	88
	1.61	7	Encased in 0.2-mm paper T=290 K after one temp cycle to 77 K.	88
(powder)	0.5-0.8	7.5	Encased in 0.05-mm-thick cellophane casing.	84
	1.0	6	Encased in glass tube T=20°C.	89
(84% 0.5 mm, 16% 0.1 mm)	0.95	22.52		85
(cast)	1.6	27.43		85
(cast, poured as cloudy slurry)	1.615	$22.0 < d_c < 25.4$	Unconfined.	23
(cast, creamed)[b]	1.605	$12.6 < d_c < 16.6$	Unconfined.	23
(cast)	1.62	14.5	Unconfined	20
(cast, poured clear at 368 K)	1.625	>31.7	Unconfined	23
(liquid)	1.443	62.6	Encased in 2.54-mm-thick glass tube.	20,39
		$30 < d_c < 32.5$	Encased in 70-mm-diam by 510-mm-long Pyrex tube T=100°C.	26
XTX-8003	1.53	0.36	Encased in polycarbonate	20
	~1.53	>0.39	at 2-mm diam.	27
XTX-8004	~1.53	~1.4	Encased in polycarbonate	27
	1.553	1.78	at 2-mm diam.	90

[a] 5-10% finely divided picric acid added to TNT melt before casting.

[b] 10% finely divided TNT added to slurry melt before casting.

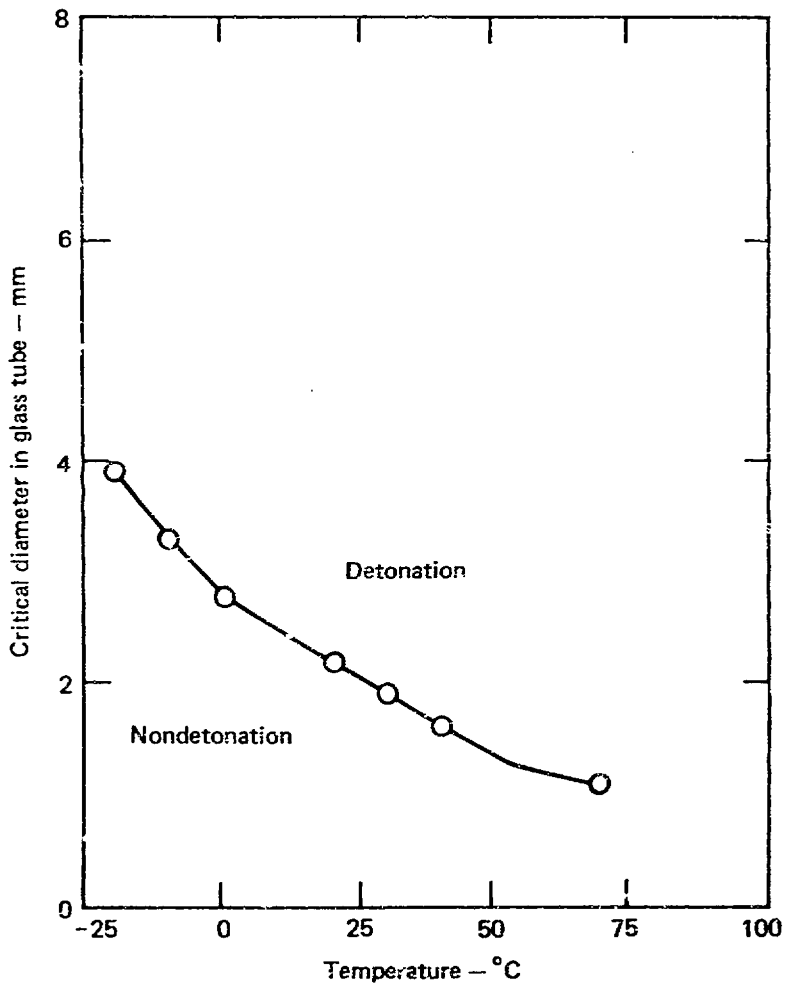


Fig. 8-2. Critical diameter of nitroglycerine as a function of temperature.[89]

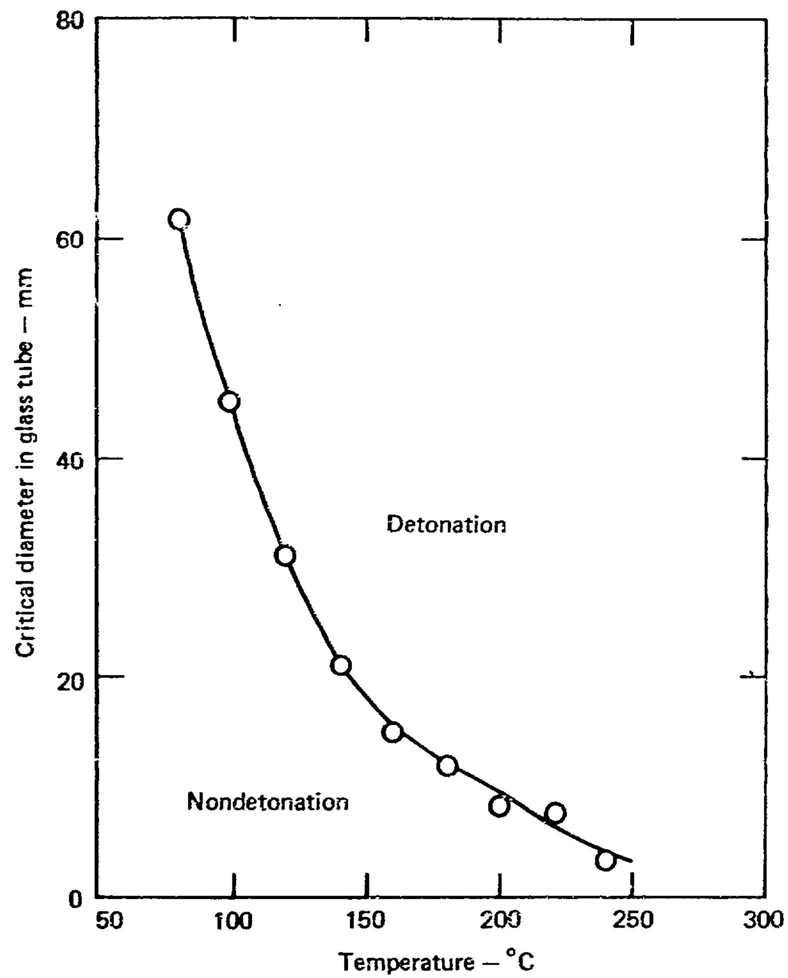


Fig. 8-3. Critical diameter of liquid TNT as a function of temperature.[89]

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9. INITIATION AND SENSITIVITY

Several tests have been designed to evaluate the sensitivity of HEs to different kinds of impact under different conditions. This section treats sensitivity of explosives in some detail in describing drop-weight impact, Susan, skid, and gap tests. The sensitivity of liquid explosives can be assessed by determining their low-velocity detonation (LVD) and high-velocity detonation (HVD) characteristics. Some critical energies for shock initiation and run distances to detonation are also given in this section.

9.1. DROP-WEIGHT TEST

The drop-weight machine, or drop hammer, offers one means of evaluating impact sensitivity. In the test, a 2.5- or 5-kg weight is dropped from a pre-set height onto a small sample of explosive (about 35-mg). A series of drops is made from different heights, and explosion or nonexplosion is recorded. The criterion for "explosion" is an arbitrarily set level of sound produced by the explosive on impact. The test results are summarized as H_{50}, the height in m at which the probability of explosion is 50%.

Values in Table 9-1 were determined on a machine patterned after the one designed at the Explosives Division, Atomic Weapons Research Establishment (AWRE), during World War II. Because of the extremely complicated process involved in initiation by impact, these drop-hammer data serve only as approximate indications of sensitivity. The H_{50} values are quite dependent on the anvil surface. Two surfaces are usually used: sandpaper (Type 12 tooling) and roughened steel (Type 12B tooling).

In general, values below 0.25 m usually indicate relative sensitivity to impact. Values between 0.25 to 0.70 m indicate a material of moderate sensitivity that possibly can be handled in accordance with standard procedures. Values above 0.70 m usually indicate relative insensitivity to impact. The maximum drop heights of the LLNL and LANL drop weight apparatus are 1.77 and 3.20 m, respectively.

The indications of sensitivity given by the drop-hammer test are always verified by large-scale testing before any material is handled in large quantities. (These tests are described below.)

Table 9-1. Drop-weight impact tests.

Explosive	H_{50} (m) 5-kg weight[a] Type 12 tooling	Type 12B tooling	2.5-kg weight[b] Type 12 tooling	Type 12B tooling
AN	--	--	1.36	>3.20
Baratol	0.95	--	0.68-1.4	0.98-1.8
Boracitol	>1.77	--	>3.20	>3.20
BTF[c]	0.11	--	~0.21	--
(fluffy powder)	--	--	2.27	--
(long needles)	--	--	1.38	~0.59
Comp A-3	--	--	0.81	2.45
Comp A-4	--	--	0.37	1.12
Comp B	0.45	--	0.49-0.85	0.98-3.0
Comp B-3	0.29	0.65	0.4-0.8	0.69-1.2
Comp C	--	--	0.42	0.36
Cyclotol 75/25	0.33	--	0.47	1.14
DATB	>1.77	>1.77	>3.20	>3.20
DIPAM	0.95	--	0.85	0.96
DNPA	>1.77	--	--	--
EDNP[d]	>1.77	--	--	--
EL-506A	0.22	--	--	--
EL-506C	0.56	--	--	--
Explosive D	--	--	1.36	>3.20
FEFO[d]	0.28	--	0.60	--
H-6	0.60	--	--	--
HMX[d]	0.33	0.40	0.32	0.30
HNAB	--	--	0.37	0.32

Table 9-1. Drop-weight impact tests (Continued)

Explosive	H_{50} (m)			
	5-kg weight[a]		2.5-kg weight[b]	
	Type 12 tooling	Type 12B tooling	Type 12 tooling	Type 12B tooling
HNS	--	--	0.54	0.66
LX-02-1	0.80	--	--	--
LX-04-1	0.41	0.55	--	--
LX-07-2	0.38	--	--	--
LX-09-0	0.32	--	--	--
LX-10-0[d]	0.35	--	0.40	--
LX-10-1	--	--	--	0.35
LX-11-0	0.59	--	--	--
LX-13 (See XTX-8003)				
LX-14-0[d]	--	--	0.53	0.51
LX-15[d]	--	--	0.83	--
LX-16	0.18	--	--	--
LX-17-0	--	--	>1.77	--
NC (11.8-12.2% N)	--	--	0.50	0.57
NG[d]	--	--	0.20	--
NM (Liquid)	--	--	>3.20	--
NQ	>1.77	--	>3.20	>3.20
Octol	0.41	--	0.35-0.52	0.49-2.7
PBX-9007	0.35	0.28	0.39	--
PBX-9010	0.30	0.45	0.31-0.41	0.31-0.92
PBX-9011	0.44	0.98	0.45-0.89	0.53-0.98
PBX-9205	0.42	0.36	0.44-0.60	0.48-0.56

Table 9-1. Drop-weight impact tests (Continued)

Explosive	H_{50} (m)			
	5-kg weight[a]		2.5-kg weight[b]	
	Type 12 tooling	Type 12B tooling	Type 12 tooling	Type 12B tooling
PBX-9404	0.34	0.35	0.33-0.48	0.35-0.57
PBX-9407	0.33	0.30	0.46	0.46
PBX-9501	0.44	0.80	0.42-0.57	0.41-0.84
PBX-9502	--	--	>3.20	>3.20
PBX-9503[e]	--	--	--	1.74[5]
Pentolite 50/50	~0.35	--	--	--
PETN	0.11	--	0.13-0.16	0.14-0.20
Picric acid	--	--	0.73	1.91
RDX	0.28	--	0.28	0.32
TATB	>1.77	--	>3.20	>3.20
Tetryl	0.28	--	0.37	0.41
TNT[c]	0.80	>1.77	1.48	~1
XTX-8003	--	--	0.31	0.42
(uncured)	0.25	--	--	--
(cured)	0.21	--	--	--
XTX-8004	--	--	0.65-0.70	1.45-1.70

[a] Reference 1.
[b] Reference 2.
[c] Reference 3.
[d] Reference 4.
[e] Reference 5.

9.2. SUSAN TEST

The Susan test[6] is a projectile impact test designed to assess the relative sensitivity of an explosive under field conditions of impact. An explosive test sample weighing about 0.9 lb (0.4 kg) is loaded into a Mod I Susan projectile (Fig. 9-1) and gunfired at the desired velocity at an armor-plate target. The resulting overpressure from the impact-induced reaction is measured using four pressure gauges about 10 ft (3 m) from the point of impact. To show the results graphically, the equivalent grams of TNT (the amount of TNT required to give the observed overpressure if detonated in the Susan test geometry) is plotted as a function of projectile velocity.

The "relative energy" values quoted in the earlier editions of this handbook (UCRL-51319 Rev. 1) cannot be translated to equivalent grams of TNT by simple arithmetic conversion (i.e., if a relative energy of 10 is equivalent to 54 g of TNT, a relative energy of 20 is equivalent to 85 g of TNT on the new scale--not to 108 g).

On the figures in this section, the explosive yield ranges from 0 to 340 g of detonated TNT. The 340-g value is arbitrarily set as the maximum Susan test reaction level, even though a larger value might be measured. Detonations rarely occur in the Susan test, but variations in sample geometry (shape) at the time of maximum-level events give variable calculated maximum yields.

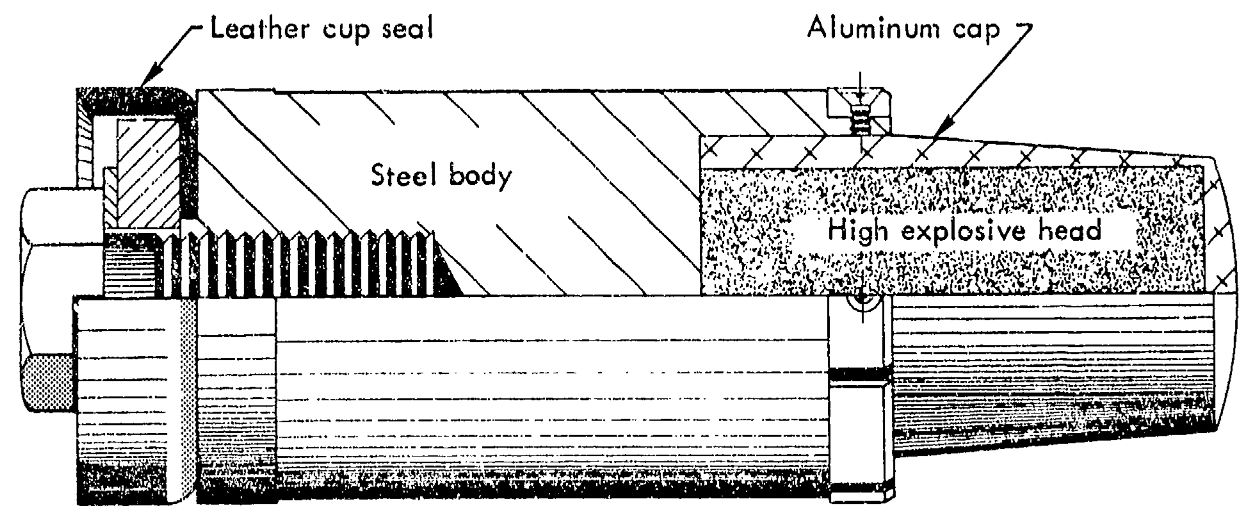


Fig. 9-1. Scaled drawing of the Susan projectile. The high explosive head is 4 in. long and 2 in. in diameter (0.102 m x 0.051 m).

Test results are summarized in Figs 9-2 through 9-6. Figure 9-2 shows the HEs that proved most sensitive in the Susan test, followed by the HE groups having high and low intermediate sensitivities (Figs. 9-3 and 9-4, respectively). The relatively insensitive explosives are grouped in Fig. 9-5, and the IHE (also called "wooden" explosives) are grouped in Fig. 9-6; all sensitivities are ranked in response to the Susan projectile impact test. The responses of LX-04-1, an HE of moderate sensitivity in this test, are plotted separately in Fig. 9-7 because many tests have been fired on this material. The relatively insensitive explosives, whose Susan test sensitivities are shown graphically in Fig. 9-5, can be divided into those having moderately low sensitivity that are used as main-charge HEs (H-6, Comp A-3) and those with low sensitivity that are useful as bomb loadings.

The following subsections supply details of the impact process pertinent to the impact safety of an explosive. Remarks about probabilities of large reactions are relevant to unconfined charges in the 25-lb (11-kg) class. Smaller unconfined charges show a trend of decreasing reaction level as the charge size decreases. References to the "pinch" stage of impact refer to the terminal stage of the test when the nose cap has completely split open longitudinally and has peeled back to the steel projectile body, which is rapidly brought to a halt.

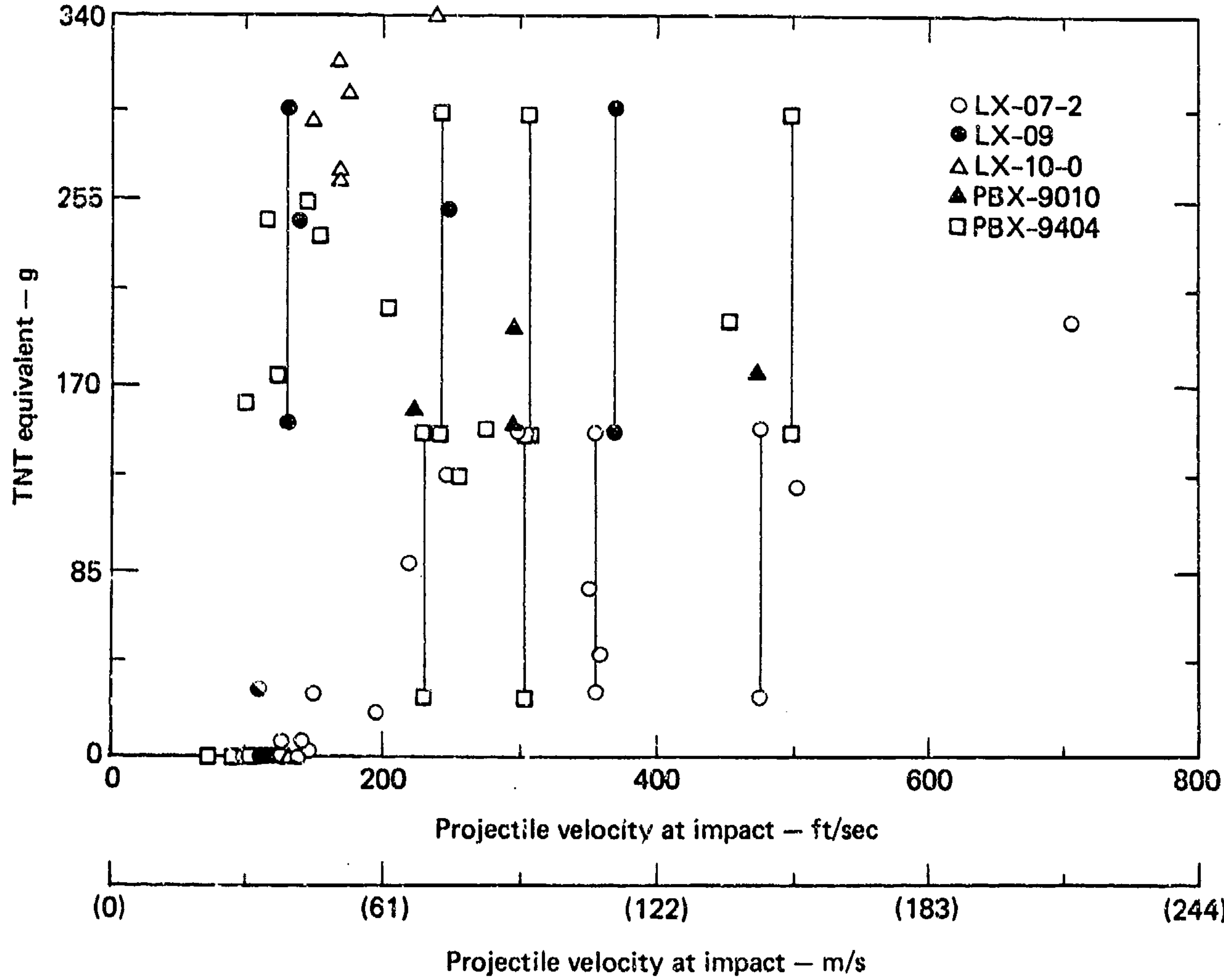


Fig. 9-2. PBXs showing high sensitivity in the Susan test. Conversion factor: 1 ft/sec = 0.3048 m/s.

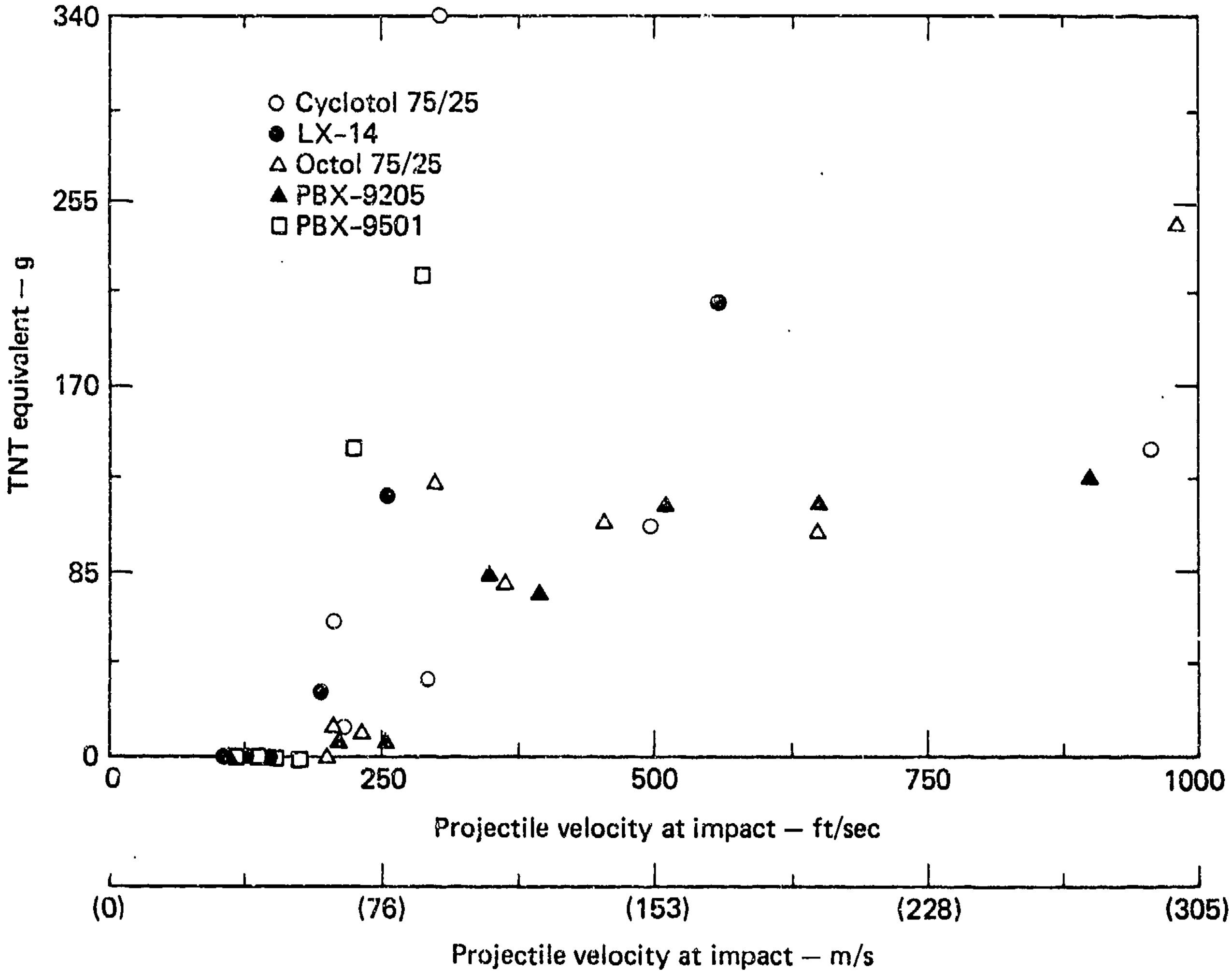


Fig. 9-3. Explosives showing somewhat lower sensitivity in the Susan test than the PBXs in Fig. 9-2. Conversion factor: 1 ft/sec = 0.3048 m/s.

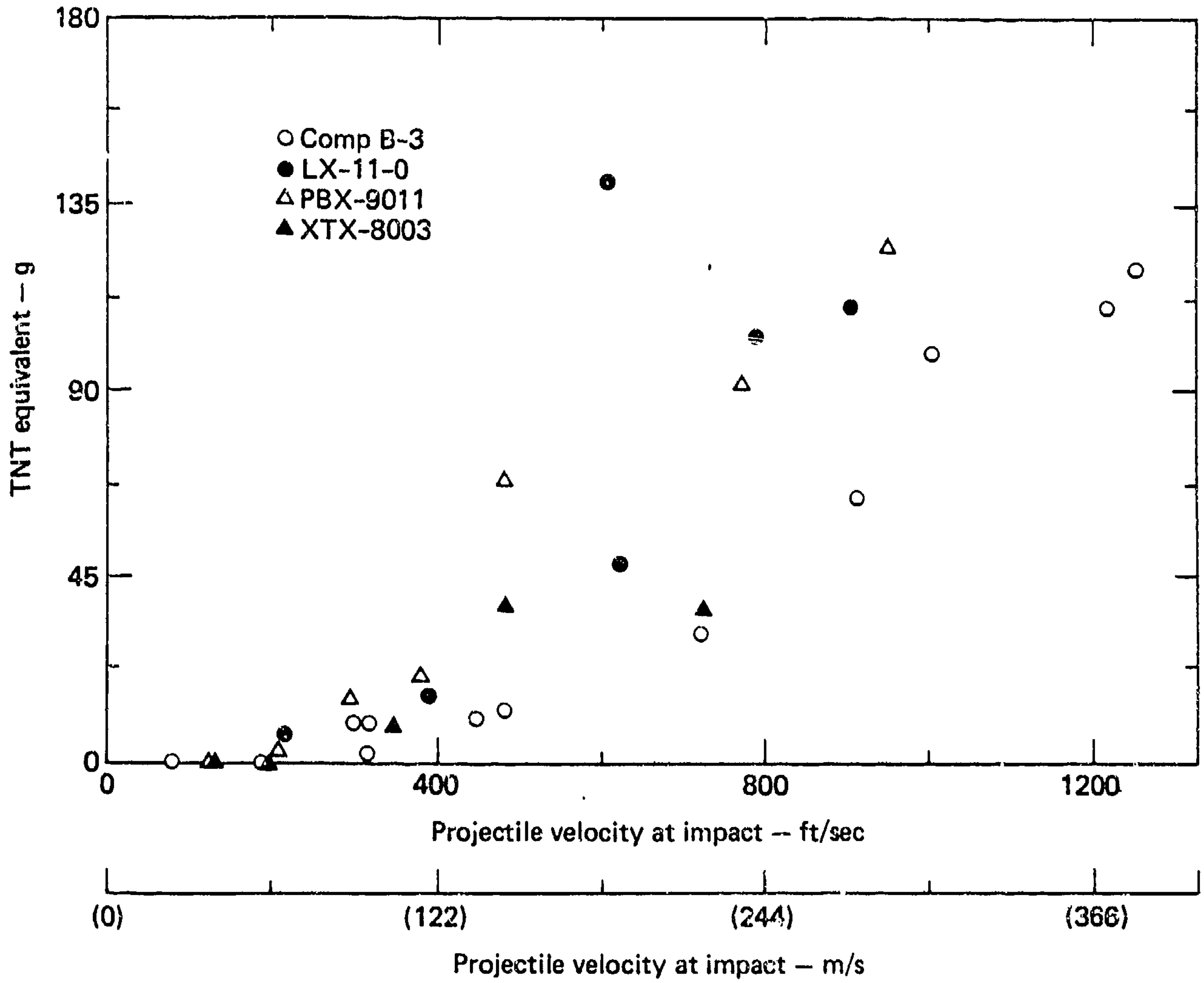


Fig. 9-4. Explosives showing sensitivities in the Susan test intermediate between the sensitive and insensitive compositions. Conversion factor: 1 ft/sec = 0.3048 m/s.

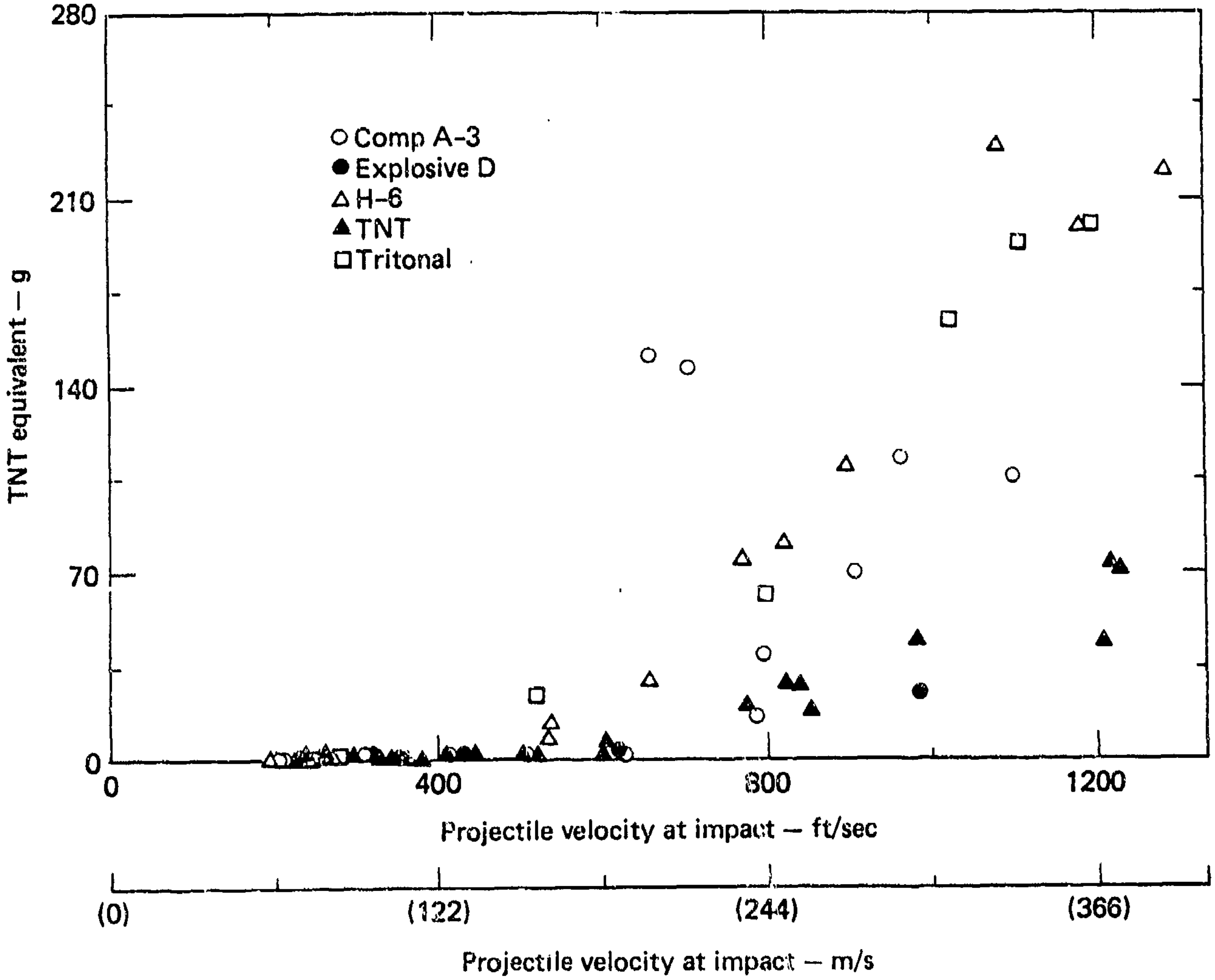


Fig. 9-5. Explosives showing relatively low sensitivity in the Susan test. Conversion factor: 1 ft/sec = 0.3048 m/s.

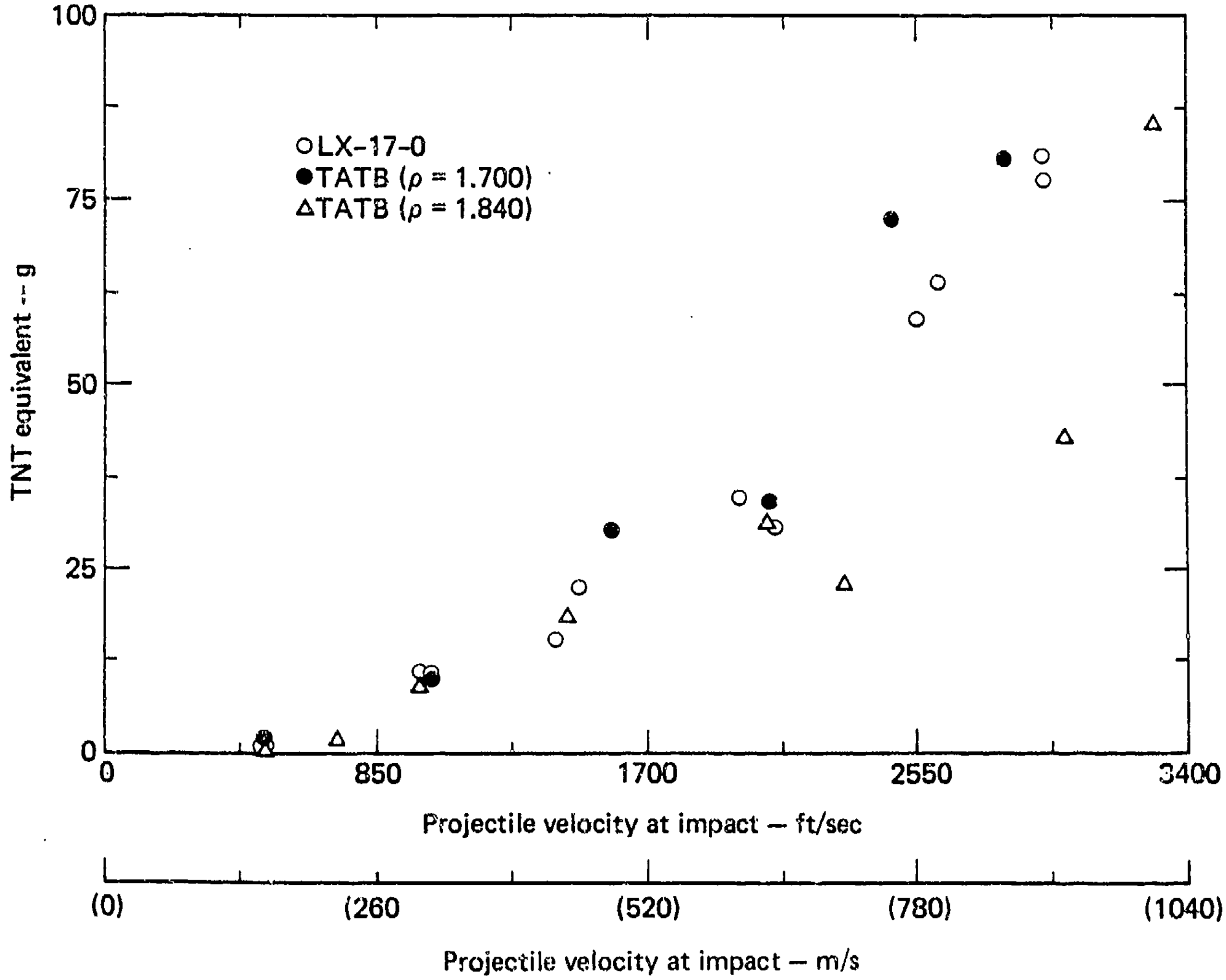


Fig. 9-6. Susan test results for insensitive explosives (IHE). Conversion factor: 1 ft/sec = 0.3048 m/s.

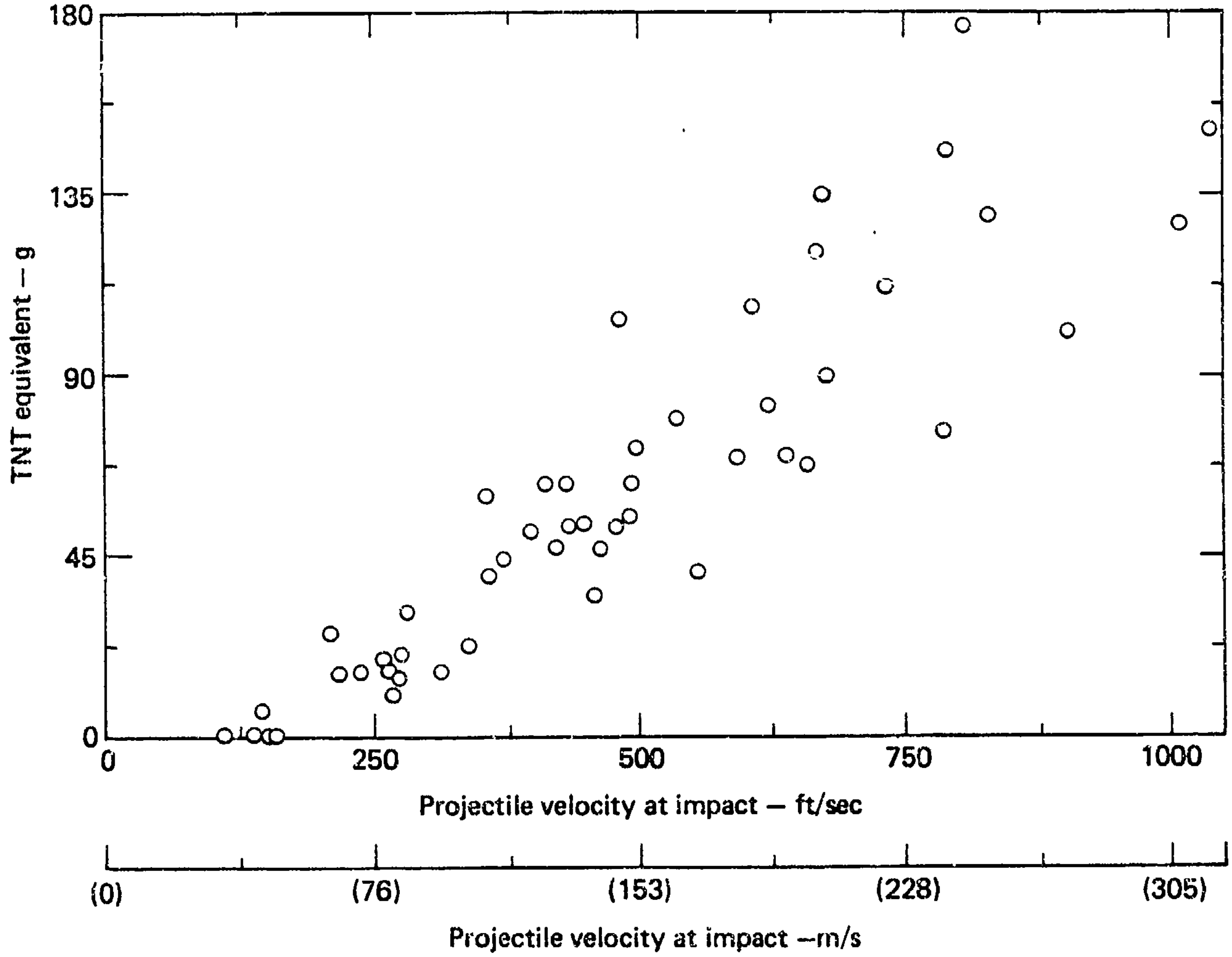


Fig. 9-7. Susan test data for LX-04. Conversion factor: 1 ft/sec = 0.3048 m/s.

9.2.1. Comp A-3

Comp A-3 has shown only minor reactions in the Susan test at impact velocities between 275 and 640 ft/sec (84 and 195 m/s) (Fig. 9-5). Three impacts at nearly 200 ft/sec (61 m/s) resulted in no detectable reaction. This low-velocity behavior is very similar to that of TNT. On the other hand, the response at higher impact velocities is generally greater than that of TNT for the same velocity, and there is occasionally a quite violent reaction. Not enough experimental data is available to determine with certainty if the higher-density Comp A-3 is more likely to give a violent reaction than the lower-density Comp A-3, although it appears that this may be so. Comp A-3 should be considered difficult to ignite by mechanical means; any reaction from such an ignition has a low probability of building to violent levels where there is relatively little confinement.

9.2.2. Comp B-3

Comp B-3 (RDX/TNT 60/40) behaves reasonably well in the Susan test (Fig. 9-4). Ignition is observed only after extensive splitting and deformation of the projectile nosecap, and it occurs more or less at the beginning of the pinch stage of impact. This results in a threshold velocity of about 180 ft/sec (55 m/s). The reaction level is quite dependent on impact velocity; it never rises to its full potential even at an impact velocity of 1500 ft/sec (457 m/s). Any reaction enhancement appears quite soon after initial ignition. Comp B-3 should be considered as generally rather difficult to ignite by mechanical means and as having a low probability for violent reaction once ignited, provided the relative confinement is rather low. It has given substantially larger reactions in the Mod-IA projectile than in the standard Mod I; the important difference between the two projectiles appears to be the exceptionally straight flight of the Mod-IA, which results in higher pressures on the explosive and more effective confinement. Comp B-3 has been observed to detonate in impact geometries where there was good inertial confinement at the time of ignition and where the impact subjected it to mechanical work.

9.2.3. Cyclotol 75/25

Cyclotol 75/25 (RDX/TNT 75/25) has both good and bad properties, as measured by the Susan test (Fig. 9-3). The threshold velocity for reaction is probably about 180 ft/sec (55 m/s), which is rather typical of the TNT-bonded cast explosives and higher than most plastic-bonded explosives. On the other hand, reaction levels generally are moderately high at relatively low velocities and on occasion are considerably higher. Cyclotol 75/25 should be considered as generally rather difficult to ignite by mechanical means but capable of a large reaction once ignited. Note that a very low drop height was sufficient for ignition in the 14-deg (0.24-rad) skid test (Table 9-2).

9.2.4. Explosive D

Explosive D has shown no undesirable properties in the Susan test. It may be somewhat less reactive than TNT, but the number of experiments is too limited to be certain (Fig. 9-5). Explosive D should be considered very difficult to ignite accidentally by mechanical means; any reaction from such an ignition has an extremely low probability of building to violent levels where there is relatively little confinement.

9.2.5. H-6

H-6 behaves very much like Comp B-3 in the Susan test at the lower impact velocities (Fig. 9-5). At the higher velocities, the reaction levels exceed those of LX-04-1 and are quite violent. H-6 should be considered difficult to ignite by mechanical means; any reaction from such an ignition has a low probability of building to violent levels where there is relatively little confinement.

9.2.6. LX-04-1

LX-04-1 (HMX/Viton 85/15) is moderately easy to ignite in the Susan test (Fig. 9-7), requiring an impact velocity of 140 to 150 ft/sec (43 to 46 m/s). At impact velocities higher than threshold, the nosecap deforms about an inch (25 mm) before ignition is observed. Reaction levels are dependent on impact velocity, rising very slowly from threshold to about 350 ft/sec (107 m/s) and then rising more rapidly as impact velocity increases. Thus, while LX-04-1 is moderately easy to ignite from mechanical impact, it has a low probability of building to a violent reaction or detonating from a minor ignition where there is little or no confinement. Note that LX-04-1 frequently has been observed to detonate high-order in other impact test geometries where the effective confinement was rather good and where the explosive was well pulverized to give a large surface area at the time of ignition.

9.2.7. LX-07-2

LX-07-2 (HMX/Viton 90/10) is intermediate in sensitivity between PBX-9404 and LX-04-1. The threshold for reaction is about 125 ft/sec (38 m/s), and the reaction level, while dependent on impact velocity, becomes large at a rather low velocity (Fig. 9-2). Small changes in manufacturing variables can affect the extent of reaction in the Susan test. The LX-07-2 initially tested was a handmade batch that gave appreciably larger reactions than previously tested LX-07-type explosives. Figure 9-2 also includes the results for LX-07-2 manufactured at the Holston Army Ammunition Plant. On the basis of the results of three shots, this material may be slightly less sensitive than the handmade batch. Thus, LX-07-2 has a low threshold for reaction but only a moderate rate of buildup to violent reaction. It appears that accidental mechanical ignition of LX-07-2 would have a moderate probability of building to violent deflagration or detonation where the relative confinement is rather low and the explosive mass relatively small.

9.2.8. LX-09-0

LX-09-0 (HMX/pDNPA/FEFO 93/4.6/2.4) displays some very undesirable properties in the Susan test (Fig. 9-2); it is very similar to PBX-9404 in many respects. Ignition occurs after about 0.5-in. (13-mm) deformation of the projectile nosecap, which is consistent with the very low threshold velocity of 110 ft/sec (34 m/s). As with PBX-9404, pinch-stage enhancement of the reaction is observed only at impact velocities greater than about 200 ft/sec (51 m/s). At lower impact velocities, reactions build to violent levels with sufficient rapidity that no pinch-stage enhancement is observed. The reaction levels observed are generally quite high and independent of impact velocity. Thus, LX-09-0 exhibits both low-threshold velocity for reaction and rapid buildup to violent reaction. Any accidental mechanical ignition has a large probability of building to a violent deflagration or detonation.

9.2.9. LX-10-0

LX-10-0 (HMX/Viton 95/5) displays some very undesirable properties in the Susan test (Fig. 9-2). Ignition is observed after about 0.6-in. (15 mm) of projectile nosecap deformation, which is consistent with the low threshold velocity of about 120 ft/sec (37 m/s). The reaction levels observed are generally quite high and independent of impact velocity. The reaction buildup is sufficiently rapid that no pinch-stage enhancement of the reaction is observed at the lower velocities. LX-10-0 exhibits both a low threshold for reaction and an extremely rapid buildup to violent reaction. Any accidental mechanical ignition of LX-10-0 has a very large probability of building to violent deflagration or detonation.

9.2.10. LX-11-0

LX-11-0 (HMX/Viton 80/20) is among the least reactive of the PBXs tested in the Susan test (Fig. 9-4). The threshold for reaction is probably about 170 ft/sec (52.8 m/s), judging from the nosecap deformation of 1.8 to 1.9 in. (46 to 49 mm) at the time ignitions were observed for the higher velocity shots. Most TNT-containing cast explosives require even more deformation for ignition; however, the reaction level is quite dependent on impact velocity and is generally lower than that observed for LX-04-1, although not as low as that observed for Comp B-3. The rather high value of 141 g of TNT-equivalent yield at 612 ft/sec (187 m/s) is considered atypical and possibly resulted from axisymmetric impact. Reaction enhancement is observed at the pinch stage of the impact. LX-11-0 should be considered as moderately difficult to ignite by mechanical means and as having very low probability of building to violent reaction from a minor ignition where there is relatively little confinement.

9.2.11. LX-14-0

LX-14-0 (HMX/Estane 95.5/4.5) is moderately easy to ignite in the Susan test, requiring an impact velocity of about 48 m/s (Fig. 9-3). This is slightly higher than that required for LX-04-1. Nosecap deformation is generally greater than 25 mm before ignition is observed. Reaction levels tend to be somewhat large once the threshold velocity is exceeded, somewhat like those of LX-07-2. In support of this tendency, skid test results on LX-14-0 are intermediate in reaction level between LX-04-1 and LX-07-2 (Table 9-2). It appears that accidental mechanical ignition of LX-14-0 has a moderately low probability of building to a violent reaction or detonation where there is little or no confinement.

9.2.12. LX-17-0

LX-17-0 (TATB/Kel-F 800 92.5/7.5), like its major component, is among the least reactive of the HEs tested in the Susan test (Fig. 9-6). The explosive response is scarcely distinguishable from that of an inert material at impact velocities up to 1000 m/s. There is no evidence of accelerated burning reactions at the higher impact velocities such as occur with almost all commonly used explosives.

9.2.13. Octol 75/25

Octol 75/25 (HMX/TNT 75/25) has both good and bad properties, as measured by the Susan test (Fig. 9-3). The threshold velocity for reaction is probably about 180 ft/sec (55 m/s), which is rather typical of the TNT-bonded cast explosives and higher than most PBXs. On the other hand, reaction levels become moderately high, generally at relatively low velocity. The variability of results is less than that observed with Cyclotol 75/25. Octol 75/25 should be considered as rather difficult to ignite accidentally by mechanical means but capable of a large reaction once ignited under certain conditions.

9.2.14. PBX-9010

PBX-9010 (RDX/Kel F 90/10) displays some very undesirable properties in the Susan test (Fig. 9-2). Ignition is observed after about 0.5-in. (13 mm) of projectile nosecap deformation, which would make the threshold velocity for reaction about 110 ft/sec (34 m/s). The reaction levels observed are high and independent of impact geometry. The observed energy release is not as high as that often seen with the more energetic explosives PBX-9404, LX-09-0, and LX-10-0, but intrinsic energy content does not completely explain the difference; geometric factors at the time of maximum reaction are thought to also contribute to the observed results. The reaction buildup is sufficiently rapid that no pinch-stage enhancement of the reaction is observed. PBX-9010 exhibits both a low threshold for reaction and sufficient reactivity to indicate a very large probability of violent reaction or detonation from any accidental mechanical ignition.

9.2.15. PBX-9011

PBX-9011 (HMX/Estane 90/10) is among the least reactive of the PBXs tested in the Susan test (Fig. 9-4). The threshold for reaction is probably about 165 ft/sec (50 m/s), judging from the nosecap deformation of about 1.7-in. (43 mm) at the time of observed ignition for the higher-velocity shots. The reaction level is quite dependent on the impact velocity; it appears to be slightly lower than that observed for LX-04-1 but not as low as for Comp B-3. Reaction enhancement is observed only at the pinch stage of the impact. PBX-9011 should be considered as moderately difficult to ignite by mechanical impact and as having very low probability of building to violent reaction from a minor ignition where there is relatively little confinement. PBX-9011 has given only mild reactions in other impact geometries that often give detonations with explosives such as LX-04-1.

9.2.16. PBX-9205

PBX-9205 (RDX/polystyrene/di-2-ethylhexylphthalate 92/6/2) is similar to LX-07-2 in some of its properties (Fig. 9-3). The threshold velocity for reaction is probably about 120 ft/sec (37 m/s), judging from the nosecap crush-up at the time of observed ignition with higher-velocity impacts. As with LX-07-2, the response is dependent on impact velocity and is intermediate between that of PBX-9404 and LX-04-1. Thus, PBX-9205 has a low threshold for reaction but only a moderate rate of buildup to violent reaction. It appears that accidental mechanical ignition of PBX-9205 has a moderate probability of building to violent deflagration or detonation.

9.2.17. PBX-9404-03

PBX-9404 (HMX/NC/tris-β-chloroethyl phosphate 94/3/3) displays some very undesirable properties in the Susan test (Fig. 9-2). Ignition is seen after only about 0.35 in. (8.9 mm) of deformation of the projectile nosecap, which is consistent with the very low threshold velocity of 105 ft/sec (32 m/s). The reaction levels are generally quite high for impacts in the range of 105 to 200 ft/sec (32 to 61 m/s). These reactions build to violent levels with sufficient rapidity that no pinch-stage enhancement of the reaction is observed. At higher impact velocities, the reaction level seems to depend somewhat on impact velocity, but it is always at least moderately high. Pinch-stage enhancement of the reaction at these higher impact velocities is very noticeable. PBX-9404 exhibits both a very low threshold velocity for reaction and rapid buildup to violent reaction. Any mechanical ignition of PBX-9404 has a very large probability of building to violent deflagration or detonation.

9.2.18. PBX-9501

PBX-9501 (HMX/Estane/BDNPA-F 95/2.5/2.5) is a high-energy explosive with low impact sensitivity for an explosive of its power (Fig. 9-3). The threshold velocity for reaction is about 200 ft/sec (61 m/s), which is higher than that for most PBXs and about equal to that for many TNT-based explosives. Reactions start after about 2.5 in. (64 mm) of projectile deformation, which is consistent with the observed threshold velocity. Once threshold velocity is exceeded, reactions become violent over a rather narrow velocity range. Small reactions do not automatically grow to large reactions as they do in many other high-energy PBXs. Skid-test ignitions, for example, give very low reactions.

9.2.19. TATB

TATB is among the least responsive of the HEs ever tested in the Susan test (Fig. 9-6). The explosive response is scarcely distinguishable from that of a mock HE at impact velocities up to 1000 m/s. There is no evidence of accelerated burning reactions at the higher impact velocities such as occur with almost all commonly used explosives.

9.2.20. TNT

TNT shows no undesirable properties by the Susan test (Fig. 9-5). Minor ignitions occur at impact velocities down to about 235 ft/sec (72 m/s) but only after extensive splitting of the projectile nosecap and abrupt halting of the projectile at the final (or pinch) stage of impact. No violent reactions are observed even at impact velocities above 1200 ft/sec (366 m/s). Further, the TNT response is independent of whether it is cast or is a high- or medium-density pressing. TNT should be considered very difficult to ignite accidentally by mechanical means; any reaction from such an ignition has an extremely low probability of building to violent levels where there is relatively little confinement.

9.2.21. Tritonal

Tritonal behaves very much like Comp B-3 in the Susan test at the lower impact velocities (Fig. 9-5). At the higher velocities the reaction levels approximate those of LX-04-1 and are quite violent. Tritonal should be considered difficult to ignite by mechanical means; and reaction from such an ignition has a low probability of building to violent levels where there is relatively little confinement.

9.2.22. XTX-8003

XTX-8003 (PETN/Sylgard 182 80/20) is moderately difficult to ignite in the Susan test (Fig. 9-4) and requires an impact velocity of about 160 ft/sec (49 m/s), judging from the 1.4-in. (36 mm) of projectile nosecap deformation at the time of observed ignition. Reaction levels ranged from quite low to moderately low over the velocity range tested. Although the number of tests is limited, it appears that XTX-8003 has a very small probability of building to violent reaction from an accidental ignition where there is relatively little or no confinement.

9.3. SKID TEST

Results from a sliding-impact sensitivity test (skid test) using large hemispherical billets of HE have proved valuable for evaluating the plant-handling safety of HEs.[7-11] The test was developed at AWRE in England.

In the LLNL-Pantex version of this test, the explosive billet, supported on a pendulum device, is allowed to swing down from preset heights and strike at an angle on a sand-coated steel target plate. The two impact angles employed [14 and 45 deg (0.79 and 0.24 rad, respectively)] are defined as the angle between the line of billet travel and the horizontal target surface. The spherical surface of the billet concentrates the force of the impact in a small area. The pendulum arrangement gives the impact a sliding or skidding component as well as a vertical one. Results of the test are expressed in terms of the type of chemical event produced by the impact as a function of impact angle and vertical drop. The chemical events are defined as follows:

- 0 No reaction; charge retains integrity.
- 1 Burn or scorch marks on HE or target; charge retains integrity.
- 2 Puff of smoke, but no flame or light visible in high-speed photography. Charge may retain integrity or may be broken into large pieces.
- 3 Mild low-order reaction with flame or light; charge broken up and scattered.
- 4 Medium low-order reaction with flame or light; major part of HE consumed.
- 5 Violent deflagration; virtually all HE consumed.
- 6 Detonation.

The sliding-impact test results are significant indications of plant-handling safety because the drop heights and impact angles used in the test are quite within the limits encountered when an explosive billet is accidentally dropped. The test is used not only to evaluate the relative sensitivity of different explosives, using the sand-coated target as a reference surface (Tables 9-2 and 9-3), but also to evaluate typical plant floor coverings, using PBX-9010 as a reference explosive (Table 9-4).

The floor-covering skid test has been modified and standardized at Pantex using results from ten 14.1-ft (4.33-m) drops of a 10.7-kg LX-10 billet at a 45-deg angle (0.79 rad) as the safety criterion (Table 9-5).[15]

Table 9-2. Standard LLNL-Pantex skid test.[a]

Explosive	Impact angle deg	(rad)	Vertical drop ft	(m)	Chemical event	Conditions
Comp B-3	14	(0.24)	0.88	(0.27)	0,0,0,0,0,0	
			1.25	(0.38)	2	
			1.25	(0.38)	0,0,0,0,0,0	-30°C (243 K)
			1.75	(0.53	0,2	-30°C (243 K)
			1.75	(0.53)	2	
			2.5	(0.76)	0,0,2,2,0,2	
			3.5	(1.07)	2,0,0,2,2	
			5.0	(1.52)	0,2,2,2,2,2	
			7.1	(2.16)	3,2	
	45	(0.79)	1.75	(0.53)	0	
			2.5	(0.76)	0	
			3.5	(1.07)	0	
			3.5	(1.07)	0,0,0	-30°C (243 K)
			5.0	(1.53)	0	
			7.1	(2.16)	0	
			10.0	(3.05)	0	
			14.1	(4.30)	2	
			20.0	(6.10)	0	
Cyclotol 75/25	14	(0.24)	0.625	(0.19)	1	
			0.88	(0.27)	4	
			1.75	(0.53)	3	
			2.5	(0.76)	3	
	45	(0.79)	5.0	(1.52)	0	
			7.1	(2.16)	0	
			14.1	(4.30)	0	
LX-04-0	14	(0.24)	1.25	(0.38)	0	
			1.75	(0.53)	2	
			2.5	(0.76)	2	
			3.5	(1.07)	2,2	
			5.0	(1.52)	2,0	
			5.0	(1.52)	0	235°F (385 K)
			7.1	(2.16)	2,2	
			10.0	(3.05)	2	
			14.1	(4.30)	2	
	45	(0.79)	3.5	(1.07)	0,1	
			3.5	(1.07)	2	-57°F (224 K)
			5.0	(1.52)	3	
			10.0	(3.05)	3	
			14.1	(4.30)	0	
			14.1	(4.30)	0	230°F (383 K)

Table 9-2. Standard LLNL-Pantex skid test.[a] (Continued)

Explosive	Impact angle deg	(rad)	Vertical drop ft	(m)	Chemical event	Conditions
LX-04-1	14	(0.24)	1.75	(0.53)	0,0	
			2.5	(0.76)	2,2,1	
			3.5	(1.07)	0	
			5.0	(1.52)	2	
			7.1	(2.16)	1	
			14.1	(4.30)	2	
	45	(0.79)	3.5	(1.07)	0,2,0,0,0	
			5.0	(1.52)	0,3,0,0,0	
			7.1	(2.16)	1,0,0	
			10.0	(3.05)	2,3	
			14.1	(4.30)	2,3	
LX-07	14	(0.24)	1.25	(0.38)	0	
			1.75	(0.53)	0	
			2.5	(0.76)	4	
			3.5	(1.07)	4	
	45	(0.79)	1.75	(0.53)	0	
			2.5	(0.76)	2	
			3.5	(1.07)	6	
LX-07-1	14	(0.24)	0.88	(0.27)	0,0,0	
			1.25	(0.38)	0,0,0	
			1.75	(0.53)	0,0,0	
			2.5	(0.76)	3,3,6	
	45	(0.79)	2.5	(0.76)	0,0	
			3.5	(1.07)	0,0,0	
			5.0	(1.52)	0,0,0	
			7.1	(2.16)	0,0,0,5,0,0	
LX-09-0	14	(0.24)	0.88	(0.27)	0,0,0,0	
			1.25	(0.38)	0,0,6	
	45	(0.79)	3.5	(1.07)	0,0,0,0,0,0,0	
			5.0	(1.52)	0,0,0,6	
			7.1	(2.16)	0	
LX-10-0	14	(0.24)	0.62	(0.19)	6	-34°C (239 K)
			0.88	(0.27)	0,0,0,0,0,0, 0,0,0,0,0,0	16°C (289 K)
			0.88	(0.27)	0,0,0,0,0,0,0	
			1.25	(0.38)	0,6,6	
			1.25	(0.38)	6,6,0	16°C (289 K)

Table 9-2. Standard LLNL-Pantex skid test.[a] (Continued)

	Impact angle		Vertical drop			
Explosive	deg	(rad)	ft	(m)	Chemical event	Conditions
LX-10-0	45	(0.79)	0.88	(0.27)	0[b]	-34°C (239 K)
			1.25	(0.38)	0[b]	-34°C (239 K)
			1.75	(0.53)	0[b]	-34°C (239 K)
			2.5	(0.76)	0,0,0	-34°C (239 K)
			2.5	(0.76)	0[b]	-34°C (239 K)
			2.5	(0.76)	0,0,0	16°C (289 K)
			2.5	(0.76)	0	71°C (344 K)
			3.5	(1.07)	0,0,0,0,6,0, 0,0,0	
			3.5	(1.07)	0[b]	-34°C (239 K)
			3.5	(1.07)	6,6,0,0,0,0, 0,0,0,0,0 0,0,0,0,0,0,0	16°C (289 K)
			3.5	(1.07)	0	71°C (344 K)
			5.0	(1.52)	6	-34°C (239 K)
			5.0	(1.52)	0	71°C (344 K)
			7.1	(2.16)	0	71°C (344 K)
LX-10-1	14	(0.24)	0.88	(0.27)	0,0,0,0,0,0,0	
			1.25	(0.38)	0,6,6,0,6,6	
			1.75	(0.53)	0,6	
	45	(0.79)	2.5	(0.76)	0,0,0	
			3.5	(1.07)	0,0,0,0,6,6,0,0	
			5.0	(1.52)	6	
LX-14-0	14	(0.24)	0.88	(0.27)	0,0,0,0,0,0	
			1.25	(0.38)	3,0,0,0	
	45	(0.79)	3.5	(1.07)	0,0,0,0,0,0	
			5.0	(1.52)	0,0,0,0,0,4	
			7.1	(2.16)	4	
LX-17-0					No reaction	
Octol 75/25	14	(0.24)	2.5	(0.76)	0	
			3.5	(1.07)	3	
PBX-9010	14	(0.24)	0.88	(0.27)	0	
			1.25	(0.38)	6,0,0,6,0,0	
			1.50	(0.46)	0,5	
			1.75	(0.53)	6,0	
			3.5	(1.07)	0	
			15.0	(4.57)	6	

Table 9-2. Standard LLNL-Pantex skid test.[a] (Continued)

Explosive	Impact angle deg	(rad)	Vertical drop ft	(m)	Chemical event	Conditions
PBX-9010	45	(0.79)	2.5	(0.76)	0,0	
			3.5	(1.07)	6,6,6,0,6	
			5.0	(1.52)	0,6,0	
			7.1	(2.16)	6	
			14.1	(4.30)	6,6	
PBX-9011	14	(0.24)	5.0	(1.52)	0	
			10.0	(3.05)	0,0	
			20.0	(6.10)	1	
			28.0	(8.53)	1	
	45	(0.79)	5.0	(1.52)	0	
			7.1	(2.16)	0	
			10.0	(3.05)	0	
			20.0	(6.10)	0	
PBX-9205	14	(0.24)	0.88	(0.27)	0	
			1.25	(0.38)	2	
			1.75	(0.53)	3	
	45	(0.79)	2.5	(0.76)	4	
PBX-9404	14	(0.24)	0.625	(0.19)	0,0,0,0,0,0	
			0.88	(0.27)	0,0,0,0,0,0,0,0,6,0,0,6	
			1.25	(0.38)	0,0,0,6,6,6	
			1.75	(0.53)	6,0,6,0,0,2,0,0,0,6	
			1.9	(0.58)	6	
			2.5	(0.76)	6,0,3,0	
			3.5	(1.07)	6,6	
	45	(0.79)	1.75	(0.53)	0,0,0,0,0,0,0	
			2.5	(0.76)	0,0,0,0,0,0,0,0,0,0	
			3.5	(1.07)	0,6,0,C,0,0,0,6,0,0 0,0,0,0,0,0,6	
			5.0	(1.52)	6,6,6,0,6,0,0,6,0,0	
			7.1	(2.16)	6,6	
			10.0	(3.05)	6,6	
			15.0	(4.75)	6	
PBX-9501	14	(0.24)	2.5	(0.76)	0,0	
			3.5	(1.07)	0,0,0	
			5.0	(1.52)	0	
			10.0	(3.05)	3	

Table 9-2. Standard LLNL-Pantex skid test.[a] (Continued)

Explosive	Impact angle deg	(rad)	Vertical drop ft	(m)	Chemical event	Conditions
PBX-9501	45	(0.79)	5.0	(1.52)	0,0,0	
			7.1	(2.16)	0,0,0	
			10.0	(3.05)	0,0,0	
(as pressed)	14	(0.24)	1.25	(0.38)	0,0,0,0,0,0	
			1.75	(0.53)	0,0,0,0,3	
			2.5	(0.76)	0,3	
	45	(0.79)	5.0	(1.52)	0,0,0,0,0,0	
			7.1	(2.16)	0,0,0,0,3	
			10.0	(3.05)	0,0,3	
			14.1	(4.30)	4	
TNT	14	(0.24)	3.5	(1.07)	0,0,0,0,0,0	
			10.0	(3.05)	2	
			14.1	(4.30)	0	
			20.0	(6.10)	0	

[a] Tests were conducted with 23-lb (10.4-kg) hemispheres of explosive 11 in. (0.28 m) in diameter at ambient temperature unless indicated otherwise. One in. = 2.54×10^{-2} m; 1 lb = 4.54×10^{-1} kg; 1 ft = 3.05×10^{-1} m; 1 deg = 1.75×10^{-2} rad.

[b] An acrid or burnt odor was noticed after the test.

Table 9-3. Nonstandard skid tests of interest.[a,12,13]

Explosive	Weight lb	(kg)	Impact angle deg	(rad)	Vertical drop ft	(m)	Chemical event	Conditions
Baratol	50	(22.7)	45	(0.79)	3	(0.9)	2	
					5	(1.5)	3	
Comp B-3	50	(22.7)	14	(0.24)	5.0	(1.52)	4	
			45	(0.79)	5.0	(1.52)	0	
					10.0	(3.05)	0,0,0,2	
Cyclotol 75/25	50	(22.7)	45	(0.79)	3.0	(0.9)	0,0,2	
					5.0	(1.52)	3,3	
LX-04-0	50	(22.7)	45	(0.79)	7.1	(2.16)	0	230°F (383 K)
LX-04-1	298	(135.2)	45	(0.79)	0.88	(0.27)	0	
					1.25	(0.38)	0	
					1.75	(0.53)	5	
LX-09-0	28	(12.7)	14	(0.24)	0.88	(0.27)	0	b
					0.88	(0.27)	6	Control
	19	(8.6)			1.25	(0.38)	0,0,0,0,0	c
					1.25	(0.38)	0,4,4,0 0,0,4	Control
	28	(12.7)	45	(0.79)	2.5	(0.76)	0	b
					2.5	(0.76)	0	Control
	19	(8.6)			2.5	(0.76)	4,0,0,0, 0,0,0,0	c
	28	(12.7)			3.5	(1.07)	6,0	b
					3.5	(1.07)	0,0	Control
	19	(8.6)			3.5	(1.07)	0,5	c
					3.5	(1.07)	5	Control
					5.0	(1.52)	4,0,5	c
					5.0	(1.52)	0,0,0	Control
LX-10-0	23	(10.4)	14	(0.24)	0.88	(0.27)	0,0,0,0	d
			45	(0.79)	3.5	(1.07)	0,0,0	
	69	(31.3)	14	(0.24)	0.44	(0.13)	0	e
	70	(31.8)			0.66	(0.20)	6	
LX-14-0	291	(132)	45	(0.79)	0.88	(0.27)	0	
	292	(132.4)			1.25	(0.38)	0	
	291	(132)			1.50	(0.46)	0	
	290	(131.6)			1.75	(0.53)	0	
					2.5	(0.76)	0	
					5.0	(1.52)	6	

Table 9-3. Nonstandard skid tests of interest.[a,12,13] (Continued)

Explosive	Weight lb	(kg)	Impact angle deg	(rad)	Vertical drop ft	(m)	Chemical event	Conditions
PBX-9404	296	(134.3)	14	(0.24)	0.25	(0.08)	0	
	292	(132.4)			0.33	(0.10)	6	
	296	(134.3)			0.48	(0.15)	6	
	296	(134.3)	45	(0.79)	0.33	(0.10)	0	
	298	(135.2)			0.44	(0.13)	0	
	293	(132.9)			0.60	(0.18)	0	
	291	(132.0)			0.63	(0.19)	0	
	287	(130.2)			1.23	(0.38)	0	
	296	(134.3)			2.5	(0.76)	0	
(as-pressed)		(13.2)	14	(0.24)	0.31	(0.09)	0	
					0.44	(0.13)	0	
					0.63	(0.19)	0	
					0.88	(0.27)	0,0,0,0,0,0	
					2.50	(0.76)	0	
					3.50	(1.07)	0,0,0,0,0,0	
					5.00	(1.52)	0,6	
PBX-9404	50	(22.7)	45	(0.79)	2.00	(0.6)	0	
					3.0	(0.9)	0,6	
					5.0	(1.5)	6	

[a] Target was standard sand-coated steel (1/4-in. (6.375-mm)) bonded to concrete. One in. = 2.54×10^{-2} m; 1 lb = 4.54×10^{-1} kg; 1 ft = 3.05×10^{-1} m; 1 deg = 1.75×10^{-2} rad.
[b] Aged 11 months at 70°C (373 K).
[c] Stockpile aged.
[d] Made with Fluorel.
[e] Made with 48 lb (21.8 kg) of steel plate on the HE equator.

Table 9-4. Evaluation of plant floorings by LLNL-Pantex test.[a,1,14,15]

Floor material	Thickness in.	(mm)	Vertical drop ft	(m)	Chemical event	Conditions
Brigantine[b]	0.090	(2.29)	7.1	(2.16)	0	New
			10.0	(3.05)	0	
			14.1	(4.3)	0	
Brigantine[b]	0.090	(2.29)	7.1	(2.16)	0	Worn
			10.0	(3.05)	1[c]	
			10.0	(3.05)	0	
			10.0	(3.05)	0	
Corrugated rubber floor covering			10.0	(3.05)	0,0	Against grain
			10.0	(3.05)	0	With grain
			20.0	(6.10)	0	
Linoleum	0.125	(3.18)	7.1	(2.16)	0	
			10.0	(3.05)	0	
			14.1	(4.30)	0	
			20.0	(6.10)	0	
Poly-Con[d]			2.5	(0.76)	0	
			3.5	(1.07)	0	
			5.0	(1.52)	0	
			7.1	(2.16)	6	
			1.25	(0.38)	0	14-deg
			1.75	(0.53)	0	(0.24-rad)
			2.5	(0.76)	0	impact
			3.5	(1.07)	0	angle
			5.0	(1.52)	6	
Quiet Zone[b]	0.17	(4.32)	7.1	(2.16)	0	New
			10.0	(3.05)	0	
			14.1	(4.3)	0	
Quiet Zone[b]	0.17	(4.32)	7.1	(2.16)	0	Worn
			10.0	(3.05)	0	
			14.1	(4.3)	0	
Sanded steel			1.75	(0.53)	0	
			2.5	(0.76)	6,6	
Torginal (Torga-Deck)	0.0625	(1.59)	14.0	(4.27)	0	
			20.0	(6.10)	6	
	(0.188	(4.76	20.0	(6.10)	0	
	to 0.25)	to 6.35)	28.0	(8.53)	1	

Table 9-4. Evaluation of plant floorings by LLNL-Pantex test.[a,1,14,15]
(Continued)

Floor material	Thickness in.	(mm)	Vertical drop ft	(m)	Chemical event	Conditions
Urapol floor covering[b]	0.094	(2.38)	10.0	(3.05)	0	
			14.1	(4.30)	0	
			20.0	(6.10)	0	
	0.125	(3.18)	10.0	(3.05)	0	
			14.1	(4.30)	0	
			20.0	(6.10)	0	
			20.0	(6.10)	0	14 deg (0.24-rad) impact angle
Vinyl			5.0	(1.52)	0,0	
			7.1	(2.16)	6,6	

a The test was conducted using 50-lb (22.7-kg) hemispheres of PBX-9010 and, except where otherwise noted, 45-deg (0.79-rad) impact angle.
One in. = 2.54×10^{-2} m; 1 lb = 4.54×10^{-1} kg; 1 ft = 3.05×10^{-1} m; 1 deg = 1.75×10^{-2} rad.
b Billet weighed 46 lb (21 kg).
c Wind-blown sand and grit on impact target may have caused this event. Wind gusting to 40 mph was evident during this test. As shown, two repetitions of this test produced no further reaction.
d A poured polyurethane floor covering.

Table 9-5. Evaluation of plant floorings by the Pantex standard test.[15]

Floor material	Thickness in.	(mm)	Chemical event	Conditions
Adiprene	0.125	(3.18)	0	With raised 1-mm buttons
DuPont entrance mat	0.094[a]	(2.38)	6	On concrete
	0.094 +0.125+0.04	(2.38+3.18+1.0)	0	On 3.18-mm-thick adiprene with raised 1-mm buttons
Flexco radial rubber tile	0.10+0.025	(2.54+0.64)	0	With raised 0.64-mm buttons
	0.185+0.025	(4.7+0.64)	0	With raised 0.64-mm buttons
	0.075+0.050	(1.9+1.3)	3	With raised 1.3-mm buttons
	0.185+0.050	(4.7+1.3)	--	With raised 1.3-mm buttons; indirect hit on third drop destroyed pad
Neoprene	0.132	(3.35)	0	3.18-mm thick, nominal
Torginal-type	0.04-0.06	(1.0-1.5)	0	2 of 10 billets cracked

[a] Foam base with intertwined rubber loops.

9.4. SHOCK INITIATION

9.4.1. Gap test

The gap test data are indicative of the shock sensitivity of an explosive. The values are reported as the thickness of an inert spacer material that has a 50% probability of allowing detonation when placed between the test explosive and a standard detonating charge. In general, the larger the spacer gap, the more shock-sensitive is the HE. The values, however, depend on test size and geometry and on the sample (the particular lot, its method of preparation, its density, and percent voids). Gap test results, therefore, are only approximate indications of relative shock sensitivity.

Tests have been developed covering a wide range of sensitivities for solid and liquid explosives at Los Alamos National Laboratory (LANL), Naval Surface Weapons Center (NSWC), Mason & Hanger-Silas Mason Co., Inc., Pantex Plant (PX), and Stanford Research Institute (SRI). Test results are listed in Table 9-6.

The test configurations are briefly described below. In all cases, detonation of the acceptor charge is ascertained by the dent produced in a "witness plate."

- NSWC small scale gap test (SSGT)[16]:

  Donor: 25.4-mm-O.D. x 38.1-mm-long RDX pellet.
  Acceptor: 25.4-mm O.D. x 38.1-mm long.
  Spacer: 25.4-mm-diam Lucite disks of different thickness.
  Results are reported in decibangs (DBG) and analyzed by the Bruceton method.

- LANL small scale gap test (SSGT)[17]:

  Donor: Modified SE-1 detonator with PBX-9407 pellet 0.300-in. diam x 0.207 in. long (7.62 x 5.26 mm).
  Acceptor: 0.5-in. diam x 1.5-in. long (12.7 x 38.1 mm).
  Spacer: Brass shims in 0.01 in. (0.25 mm) increments.
  Results are reported in in. (mm) and analyzed by the Bruceton method.

- LANL large scale gap test (LSGT)[17]:

Donor: 1.625-in.-diam x 4-in.-long (41.3 x 102 mm) PBX-9205 pellet.
Acceptor: 1.625-in. diam x 4-in. long (41.3 x 102 mm).
Spacer: 1.625-in.-diam (41.3 mm) disks of 2020-T4 Dural (aluminum).
Results are reported in in. (mm) and analyzed by the Bruceton method.

- PX gap test[18]:

Donor: 25.4-mm-diam x 38.1-mm-long LX-04 pellet.
Acceptor: 25.4 x 25.4-mm right cylinder.
Spacer: 25.4-mm-diam brass shims in 0.25-mm increments.
Results are reported in in. (mm) and analyzed by the Bruceton method.

- SRI gap test for liquid HE[19]:

Donor: Two 1.625-in.-diam x 0.5-in.-long (41.3 x 12.7 mm) Tetryl pellets, each weighing about 50 g.
Acceptor: 0.5-in.-I.D. x 0.1-in.-thick x 4-in.-long (12.7 x 2.54 x 102 mm) steel tubes.
Spacer: 0.01-in.-thick x 1.625-in.-diam (0.25 x 41.3 mm) cellulose acetate disks, called "cards", used here as a unit of measurement.

Table 9-6a. NSWC small scale gap tests.[16]

Explosive	Density, ρ [g/cm³ (Mg/m³)]	Percent voids %	Loading pressure ksi	Loading pressure (MPa)	Sensitivity DBG[a]	Sensitivity (mm)
Comp A-5	1.700	4.5	16	110	4.616	(8.79)
Comp B	1.735	0	64	441	7.277	(4.75)
	1.473	14.4	4	28	4.904	(8.20)
Comp C-3	1.612	--	4	28	7.510	(4.50)
Comp C-4	1.643	--	4	28	8.508	(3.53)
DATB	1.775	3.5	64	441	8.882	(3.28)
	1.233	33	4	28	6.909	(5.18)
DIPAM	1.784	0.3	64	441	7.539	(4.48)
	1.216	32.1	4	28	5.233	(7.62)
H-6	1.708	5.1	40	276	7.182	(4.85)
HBX-3	1.827	3.3	--	--	9.938	(2.57)
	1.732	5.9	50	345	8.535	(3.56)
HMX	1.814	4.7	64	441	4.644	(8.71)
	1.517	20.3	8	55	3.526	(11.28)
HNAB	1.774	--	64	441	6.003	(6.38)
	1.383	--	4	28	3.244	(12.04)
HNS-I	1.694	2.6	64	441	6.903	(5.18)
	1.122	35.5	4	28	5.556	(7.06)
HNS-II	1.725	0.9	64	441	6.684	(5.46)
	1.644	--	32	221	--	(7.52)
	1.322	24.0	4	28	4.264	(9.53)
Lead azide (dext.)	3.663	22.2	64	441	-0.303	(27.23)
	2.535	46.2	4	28	-3.622	(58.50)
LX-04-0	1.828	3.3	64	441	6.199	(6.10)
NQ (bulk)	1.273	28.5	8	55	9.689	(2.72)
(bulk)	0.954	46.4	1.3	9	6.387	(5.84)
Octol 75/25	1.829	0	64	441	7.086	(4.88)
	1.541	15.8	4	28	3.795	(10.90)

Table 9-6a. NSWC small scale gap tests.[16] (Continued)

Explosive	Density, ρ [g/cm³ (Mg/m³)]	Percent voids %	Loading pressure ksi	(MPa)	Sensitivity DBG[a]	(mm)
PBX-9407	1.755	3.0	64	441	5.884	(6.55)
	1.653	8.7	32	221	5.008	(6.03)
	1.269	29.9	4	28	3.627	(11.02)
Pentolite 50/50	1.671	2.3	32	221	4.030	(10.03)
	1.363	30.3	4	28	3.097	(12.45)
PETN	1.775	0.3	64	441	4.998	(6.03)
	1.576	11.5	16	110	2.476	(14.38)
	1.355	27.9	4	28	2.726	(13.56)
RDX	1.717	4.7	38.2	263	5.073	(7.90)
	1.546	14.2	10	69	3.250	(12.01)
	1.188	34.1	2	14	3.569	(11.18)
TACOT	1.698	8.2	64	441	7.487	(4.52)
	1.162	37.2	4	28	5.562	(7.06)
TATB	1.887	2.2	64	441	13.604	(1.12)
	1.519	21.3	4	28	7.918	(4.12)
Tetryl	1.687	2.5	32	221	5.133	(7.80)
	1.434	17.1	4	28	3.267	(11.96)
TNT	1.651	0	64	441	8.066	(3.96)
	1.561	5.5	19	131	6.095	(6.25)
	1.353	18.0	4	28	5.067	(7.90)

[a] 1 DBG = 30 - 10 log gap (10^{-3} in.).

Table 9-6b. LANL small scale gap tests.[1,17]

Explosive	Preparation	Density, ρ [g/cm³ (Mg/m³)]	Percent voids (%)	50% point mils	50% point (mm)
Baratol	Cast	2.565	2.6	--	NO GO
Comp A-3	Hot-pressed	1.635	3.1	--	(0.89)
	Bulk	0.90	46.7	--	(0.64)
Comp B, Grade A	Vacuum cast	1.710	1.5	--	(0.53)
Comp B-3	Cast	1.72	1.8	--	(1.22)
Cyclotol 75/25	Cast	1.752	1.1	--	(0.34)
DATB	Hot-pressed	1.801	2.0	--	(0.36)
	Hot-pressed	1.714	6.7	--	(1.22)
Explosive D	Hot-pressed	1.675	2.4	--	(0.51)
	Hot-pressed	1.604	6.6	--	(0.13)
	Bulk	1.05	38.8	--	NO GO
HMX	Hot-pressed	1.840	3.2	--	(3.43)
	Hot-pressed	1.790	5.8	--	(4.27)
	Bulk (coarse)	1.20	36.8	--	(8.53)
	Flash-crystallized (fine)	0.7	63	--	(6.45)
HNAB[20]	Pressed	1.601	--	219	(5.6)
HNS-I[21]		1.669	4.1	208	(5.28)
		1.566	10	230	(5.84)
		1.376	20.9	264	(6.71)
LX-04-0	Hot-pressed	1.852	2.1	--	(2.41)
	Hot-pressed	1.840	2.7	--	(2.31)
LX-04-1	Hot-pressed	1.868	1.4	--	(1.78)
(pre-6/65)	Hot-pressed	1.865	1.3	60-80	(1.5-2.0)
(post-6/65)	Hot-pressed	1.865	1.3	40-60	(1.0-1.5)
LX-07-1	Hot-pressed	1.857	1.8	70-90	(1.8-2.3)
LX-07-2	Hot-pressed	1.859	1.3	70-90	(1.8-2.3)
LX-09-0	Hot-pressed	1.835	1.3	75-105	(1.9-2.7)
LX-10-0	Hot-pressed	1.872	1.7	80-100	(2.0-2.5)
	Hot-pressed	1.857	2.1	--	(2.29)
LX-11-0	Hot-pressed	1.867	0.3	45-65	(1.1-1.7)

Table 9-6b. LANL small scale gap tests.[1,17] (Continued)

Explosive	Preparation	Density, ρ [g/cm^3 (Mg/m^3)]	Percent voids (%)	50% point mils	50% point (mm)
LX-13 (See XTX-8003)					
LX-14	Hot-pressed	1.833	0.9	60-80	(1.5-2.0)
LX-15[21]		--	--	234	(5.94)
NM (mod. test)[a]	--	--	--	7-17	(0.18-0.43)
(mod. test)[b]	--	--	--	2-8	(0.05-0.20)
NQ	Hot-pressed	1.575	11.8	--	NO GO
Octol 75/25	Vacuum cast	1.810	1.4	--	(0.58)
PBX-9007	Hot-pressed	1.638	3.4	--	(2.01)
PBX-9010-02	Hot-pressed	1.783	1.7	--	(2.16)
	Hot-pressed	1.742	4.0	--	(2.72)
	Bulk	0.88	51.5	--	(5.16)
PBX-0911-03	Hot-pressed	1.783	0.7	--	(1.60)
	Hot-pressed	1.731	3.5	--	(1.75)
PBX-9205	Hot-pressed	1.682	1.6	--	(0.76)
	Bulk	0.91	46.7	--	(7.52)
PBX-9404-03	Hot-pressed	1.850	0.9	--	(2.44)
	Cold-pressed	1.801	3.5	--	(2.97)
	Hot-pressed	1.792	4.0	--	(3.40)
PBX-9407	Hot-pressed	1.770	1.8	--	(2.57)
	Hot-pressed	1.696	5.9	--	(3.91)
	Cold-pressed	1.598	11.4	--	(5.13)
	Bulk	0.68	62.3	--	(6.63)
PBX-9501	Hot-pressed	1.843	0.6	50-70	(1.3-1.8)
	Hot-pressed	1.825	1.3	--	(1.52)
Pentolite 50/50	Vacuum Cast	1.700	0.9	--	(0.86)
	Hot-pressed	1.676	2.0	--	(3.12)
	Bulk	0.75	56.1	--	(4.80)
PETN	Hot-pressed	1.757	0.7	--	(5.21)
	Bulk (coarse)	0.89	49.7	--	(9.30)

Table 9-6b. LANL small scale gap tests.[a,b] (Continued)

Explosive	Preparation	Density, ρ [g/cm^3 (Mg/m^3)]	Percent voids (%)	50% point mils	(mm)
RDX	Hot-pressed	1.735	4.1	--	(5.18)
	Bulk (coarse)	1.11	38.7	--	(8.86)
	Bulk (fine)	1.00	44.8	--	(7.82)
	Flash-crystal-ized (fine)	0.7	61	--	(6.77)
TATB	Hot-pressed	1.872	3.4	--	(0.13)
Tetryl	Hot-pressed	1.684	2.7	--	(3.84)
	Hot-pressed	1.676	3.1	--	(4.04)
	Bulk	0.93	46.2	--	(7.44)
TNT	Hot-pressed	1.633	1.3	--	(0 33)
	Bulk (flake)	0.84	49.2	--	NO GO
	Bulk (granular)	0.77	53.4	--	(4.11)
XTX-8003	Uncured	1.53	1.7	160-190	(4.1-4.8)
	Cured	1.53	1.7	130-160	(3.3-4.1)

[a]In brass sleeve 0.200 in. I.D. x 0.147 in. thick (5.08 by 3.73 mm).

[b]In brass sleeve 0.400 in I.D. x 0.43 in. thick (10.2 by 10.9 mm).

Table 9-6c. LANL large scale gap tests.[1,17]

Explosive	Preparation	Density, ρ [g/cm^3 (Mg/m^3)]	Percent voids (%)	50% point in.	50% point (mm)
Baratol	Vacuum cast	2.597	1.4	1.705	(27.30)
Comp A-3	Pressed	1.638	2.9	--	(54.51)
Comp B, Grade A	Cast	1.712	2.2	1.755	(44.58)
Comp B-3	Cast	1.727	1.4	1.982	(50.34)
Cyclotol 75/25	Cast	1.757	0.6	1.699	(43.15)
	Cast	1.734	2.2	1.801	(45.74)
DATB	Hot-pressed	1.786	2.8	1.641	(41.68)
	Hot-pressed	1.705	7.2	1.786	(45.36)
	Bulk	0.81	56.0	1.940	(49.3)
Explosive D	Pressed	1.668	2.9	--	(42.42)
	Pressed	1.604	6.6	--	(42.98)
HMX		1.07	43.7	2.783	(70.7)
LX-04-0	Pressed	1.853	2.1	--	(50.16)
LX-04-1	Pressed	1.855	2.1	2.036	(51.71)
LX-09-0	Hot-pressed	1.834	1.8	--	(58.47)
NQ	Pressed	1.715	3.5	NO GO	--
	Pressed	1.609	9.6	0.197	(5.00)
Octol					
(regular HMX)	Cast	1.822	0.7	1.947	(49.45)
(large HMX)	Cast	1.815	1.4	1.863	(47.32)
	Vacuum cast	1.795	2.0	--	(43.56)
PBX-9007	Pressed	1.646	2.9	--	(52.91)
PBX-9010-01	Pressed	1.786	1.5	2.090	(53.09)
	Bulk	0.81	55.3	2.654	(67.4)
PBX-9010-02	Pressed	1.782	1.8	2.157	(54.79)
	Bulk	0.85	53.1	2.617	(66.5)
PBX-9011	Pressed	1.761	1.9	--	(51.97)
PBX-9205	Pressed	1.682	1.6	2.001	(50.83)

Table 9-6c. LANL large scale gap tests.[1,17] (Continued)

Explosive	Preparation	Density, ρ [g/cm^3 (Mg/m^3)]	Percent voids (%)	50% point in.	50% point (mm)
PBX-9404-03	Biomodel HMX, pressed	1.841	1.3	2.268	(57.61)
	Slurry mix, pressed	1.825	2.2	2.223	(56.46)
	Ground, pressed	1.755	5.9	2.410	(61.21)
	Ground, pressed	1.400	25.0	2.483	(63.07)
	Ground, pressed	1.230	34.1	2.526	(64.16)
	Ground bulk, pressed	0.920	50.7	2.694	(68.43)
PBX-9407	Pressed	1.772	1.7	2.155	(54.74)
	Bulk	0.60	66.7	2.455	(62.4)
PBX-9502	Pressed	1.895	2.4	0.879	(22.33)
PBX-9503	Pressed	1.88	2.9	--	(42.8)
	Pressed	1.59	17.9	--	(47.0)
Pentolite 50/50	Cast	1.702	0.8	2.549	(64.74)
	Pressed	1.635	4.4	2.703	(68.66)
PETN	Raw	0.81	54.2	2.732	(69.4)
RDX	Pressed	1.750	3.3	2.434	(61.82)
		1.09	39.8	2.764	(70.2)
TATB	Pressed	1.870	3.6	0.863	(21.92)
Tetryl	Hot-pressed	1.690	2.3	--	(59.82)
	Pressed	1.666	3.7	2.386	(60.60)
		0.85	50.9	2.725	(69.2)
TNT	Pressed at 70°	1.626	1.7	1.944	(49.38)
	Cast	1.615	2.4	1.114	(28.30)
	Creamed	1.582	4.2	0.814	(20.68)
	Pressed at 65°C	1.631	1.4	1.828	(46.43)
	Pressed at 25°C	1.505	9.0	--	(54.92)
	Pressed at 25°C	1.220	26.2	--	(56.26)
	Flake	0.87	47.4	1.460	(37.1)
	Granular	0.73	55.9	2.268	(60.8)
Tritonal	Cast	1.792	~1.0	0.870	(22.10)

Table 9-6d. PX gap tests for insensitive HE.

Explosive	Preparation	Density, ρ [g/cm³ (Mg/m³)]	Percent voids (%)	50% point in.	50% point (mm)
Baratol[18]	Machined	2.610	0.7	--	(8.76)
Comp B[22]	Cast	1.714	2.2	--	(23.2)
DATB[22]		1.781	3.2	--	(17.86)
		1.446	21.3	--	(19.94)
LX-04[23]	Machined	1.862	1.4	--	(20.3)
LX-17-0[23]	Pressed	1.902	--	--	(1.35)
	Machined	1.899	--	--	(2.29)
PBX-9404[22]	Pressed	--	--	--	(27.3)
PBX-9502[23]		1.884	2.4	--	(2.11)
TATB[18,23]	Pressed	1.883	--	--	(~5.3)
	Pressed	1.861	4.0	--	(5.61)
	Pressed	1.700	12.3	--	(14.10)
	Bulk	1.03	--	--	(10.2-16.3)

Table 9-6e. SRI gap test sensitivities of liquid explosives.[19]

Explosive	LVD gap cards[a]	LVD gap (mm)	HVD gap cards[a]	HVD gap (mm)	HVD velocity (km/s)
FEFO	1500-1800	(381-457)	77	(19.6)	7.2
FEFO/AFNOL 87/13	--	--	<70	(<17.5)	--
NG/EGDN 50/50	11,000	(2790)	180	(45.7)	7.61
NM	--	--	20-44	(5.1-10.2)	6.3
NM/TNM 50/50	354-394	(90-100)	40	(10)	7.4

[a]Cellulose acetate disk, .010 in. thick

9.4.2. Critical energy

Data from a number of sources show that a rather strict boundary exists between shock initiation and noninitiation of an explosive when critical energy is plotted as a function of the energy fluence of the shock wave. Each explosive studied has a specific critical energy fluence value. Critical energy as a function of pressure and time has not been explored widely, but the data to date indicate that the critical energy fluence for initiation is probably reasonably constant over the initiation-pressure ranges of interest.[24] A critical energy equation has been derived from the conservation and Hugoniot relationships. The equation is:

$$E_c = \frac{tP^2}{\rho U_s} ,$$

where

- E_c = critical energy in cal/cm^2 (J/m^2),
- t = pulse-width of the incident shock in μs,
- P = shock pressure in kbar (GPa),
- ρ = density of the explosive in g/cm^3 (Mg/m^3),
- U_s = shock velocity in cm/μsec (km/s) in the explosive at pressure P.

Table 9-7 gives the E_c values for several HEs.

Table 9-7. Critical energies for shock initiation.

Explosive	Density, ρ [g/cm^3 (Mg/m^3)]	E_c[a] [cal/cm^2 (kJ/m^2)]	Ref.
Comp B	1.73	44 (1850)	39
Comp B-3	1.727	33 (1381)	38
DATB	1.676	39 (1632)	24
HNS-I	1.555	<34 (<1422)	
Lead azide	4.93	0.03 (1.255)[b]	24
LX-04	1.865	26 (1090)	24
LX-09	1.84	23 (962)	26
NM	1.13	404.7 (17,000)[b]	24
PBX-9404	1.84	15 (630)	24
	1.842	15 (644)	27
PETN	≈1.0	∿2 (∿84)	24
	1.0	2.7 (120)	24
	≈1.6	∿4 (∿167)	24
RDX	1.55	(680)[c]	38
TATB	1.93	226 (9500)[b]	24
	1.762	72-88 (3013-3682)	24
Tetryl	1.655	10 (420)	28
TNT (cast)	1.6	100 (4200)[b]	29
	1.620	32 (1339)	24
(pressed)	1.645	34 (1420)	24

[a] One cal/cm^2 = 4.184×10^4 J/m^2.

[b] Values were estimated from data other than critical energy determinations and should be considered tentative.

[c] Constant energy threshold not confirmed.

9.4.3. LVD screening test

A donor-acceptor test was developed at LLNL to determine the relative shock sensitivities of liquid explosives.[30] In this test, a thin, wedge-shaped film is spread on an aluminum tray, which also serves as a witness plate. The sample is initiated by a donor system consisting of a detonator and a variable-PETN-content booster. The booster pellet varies from 20 to 100 wt% PETN (ρ = 0.95 Mg/m^3), and the output pressure varies from 4.9 to 17.9 GPa. Transitions between HVD, LVD, and failure are discernible on the witness plate. Transition thresholds and failure are shown in Table 9-8 as a function of output pressure.

Table 9-8. Pressure at transition threshold and detonation failure thickness.

Liquid HE	Density, ρ [g/cm^3 (Mg/m^3)]	Pressure (GPa)	HVD	Failure thickness (mm)	LVD	Failure thickness (mm)
NG	1.6	<4.9	NO GO	--	GO	0.0
	1.6	<4.9	HVD	0.6	GO	0.0
FEFO	1.6	8.9	NO GO	--	GO	0.0
	1.6	17.1	HVD	2.8	GO	0.2

9.4.4. Initial shock pressure

Shock initiation experiments, such as wedge tests, provide records of initial shock pressure-distance histories characteristic to each HE. The log P-log x equations in Table 9-9 represent least squares fits in the pressure ranges indicated.[31] The $P\text{-}x^{-1}$ equations in the table represent least squares fits for runs (x) of less than 25 mm. Some of the fits are shown graphically in Figs. 9-21a through 9-21d, known as Pop plots.

Table 9-9. Least squares fits for shock initiation data.[31-33,37]

Explosive	Density, ρ [g/cm^3 (Mg/m^3)]	Equation[a]	Pressure Range, P (GPa)
Baratol	2.611	$\log P = 1.2352 - 0.3383 \log x$	$6.8 \leq P \leq 12$
		$P = 5.44 + 22.47\ x^{-1}$	$6.8 \leq P \leq 12$
Comp B	1.72	$\log P = 1.5587 - 0.7614 \log x$	$3.7 < P < 12.6$
HMX	1.891	$\log P = 1.18 - 0.59 \log x$	$4.4 < P < 9.6$
LX-04-1	1.862	$\log P = 1.338 - 0.656 \log x$	$6.8 < P < 16.7$
LX-17	1.90	$\log P = 1.4925 - 0.5657 \log x$	$6 < P < 23.5$
NQ (large grain)	1.659-1.723	$\log P = 1.44 - 0.15 \log x$	$13.4 < P < 26.3$
(commercial)	1.688	$\log P = 1.51 - 0.26 \log x$	$21.2 < P < 29.1$
PBX-9011-06	1.790	$\log P = 1.1835 - 0.6570 \log x$	$4.8 \leq P \leq 16$
		$P = 2.59 + 13.55\ x$	$4.8 \leq P \leq 16$
PBX-9404	1.840	$\log P = 1.1192 - 0.6696 \log x$	$2 \leq P \leq 25$
		$P = 2.17 + 9.88\ x^{-1}$	$3 \leq P \leq 25$
	1.721	$\log P = 0.9597 - 0.7148 \log x$	$1.2 \leq P \leq 6.3$
		$P = 1.09 + 8.71\ x^{-1}$	$2.0 \leq P \leq 6.3$
PBX-9407	1.60	$\log P = 0.57 - 0.49 \log x$	$1.4 < P < 4.7$
PBX-9501-01	1.833	$\log P = 1.0999 - 0.5878 \log x$	$2.5 \leq P \leq 6.9$
	1.844	$\log P = 1.1029 - 0.5064 \log x$	$2.5 \leq P \leq 7.2$
PBX-9502	1.896	$\log P = 1.39 - 0.31 \log x$	$10.1 < P < 15$

Table 9-9. Least squares fits for shock initiation data.[31-33,37] (Continued)

Explosive	Density, ρ [g/cm³ (Mg/m³)]	Equation[a]	Pressure Range, P (GPa)
PETN	1.75	$\log P = 0.57 - 0.41 \log x$	$1.7 < P < 2.6$
	1.72	$\log P = 0.6526 - 0.5959 \log x$	$2.0 \leq P \leq 4.2$
	1.60	$\log P = 0.3872 - 0.5038 \log x$	$1.2 \leq P \leq 2.0$
	1.0	$\log P = -0.3855 - 0.2916 \log x$	$0.2 \leq P \leq 0.5$
TATB	1.876	$\log P = 1.4170 - 0.4030 \log x$	$11 \leq P \leq 16$
		$P = 8.24 + 26.01\, x^{-1}$	$11 \leq P \leq 16$
(superfine)	1.81	$\log P = 1.31 - 0.43 \log x$	$10 < P < 28$
(micronized)	1.81	$\log P = 1.41 - 0.38 \log x$	$14.3 < P < 27.8$
Tetryl	1.70	$\log P = 0.79 - 0.42 \log x$	$2.2 < P < 8.5$
	1.30	$\log P = 0.87 - 1.11 \log x$	$0.37 < P < 6.9$
TNT (cast)	1.635	$\log P = 1.40 - 0.32 \log x$	$9.2 < P < 17.1$
(pressed)	1.63	$\log P = 1.0792 - 0.3919 \log x$	$4 < P < 12$
XTX-8003	1.53	$\log P = 0.7957 - 0.463 \log x$	$3.0 \leq P \leq 5.0$

[a]Where x = run distance to detonation in mm; P = initial shock pressure in GPa.

Fig. 9-21a. Pop plots of representative explosives.

Curve number	Explosive	Density (ρ) [g/cm^3 (Mg/m^3)]	Ref.
1	Baratol (cast)	2.6-2.62	37
2	Comp B	1.72	34
3	LX-17	1.90	23
4	PBX-9404	1.84	37
5	PBX-9407	1.6	37
6	Tetryl	1.70	37
7	Tetryl	1.30	37
8	TNT (cast)	1.62-1.63[a]	37
9	TNT (pressed)	1.63	34

[a] 25-73°C.

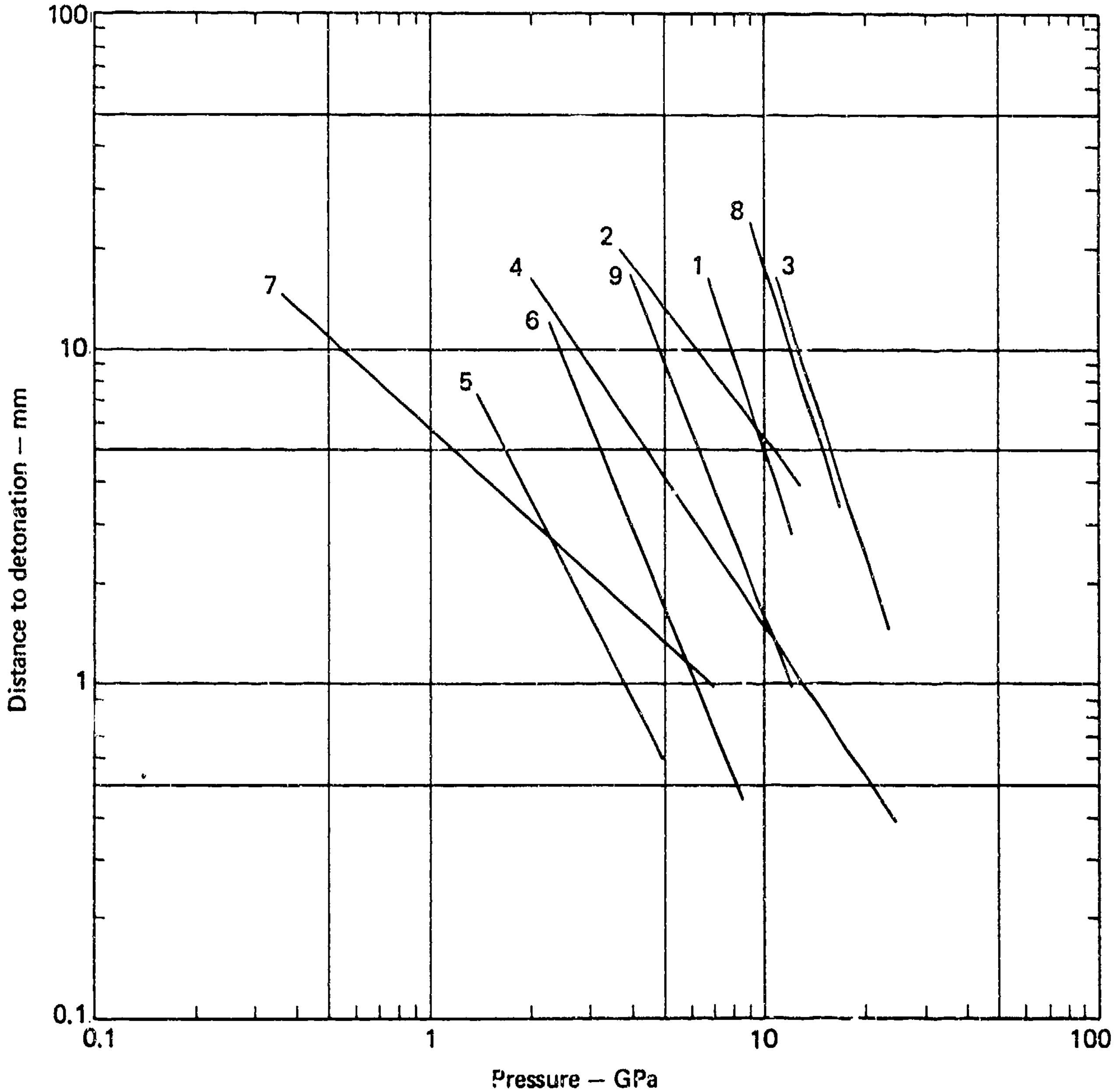


Fig. 9-21a. (Continued)

Fig. 9-21b. PETN and PETN-based explosives as a function of density.

Curve number	Explosive	Density (ρ) [g/cm^3 (Mg/m^3)]	Ref.
1	PETN	1.0	33,34
2	PETN	1.6	33,36
3	PETN	1.72	33,36
4	PETN	1.75	36
5	XTX-8003	1.53	33,37

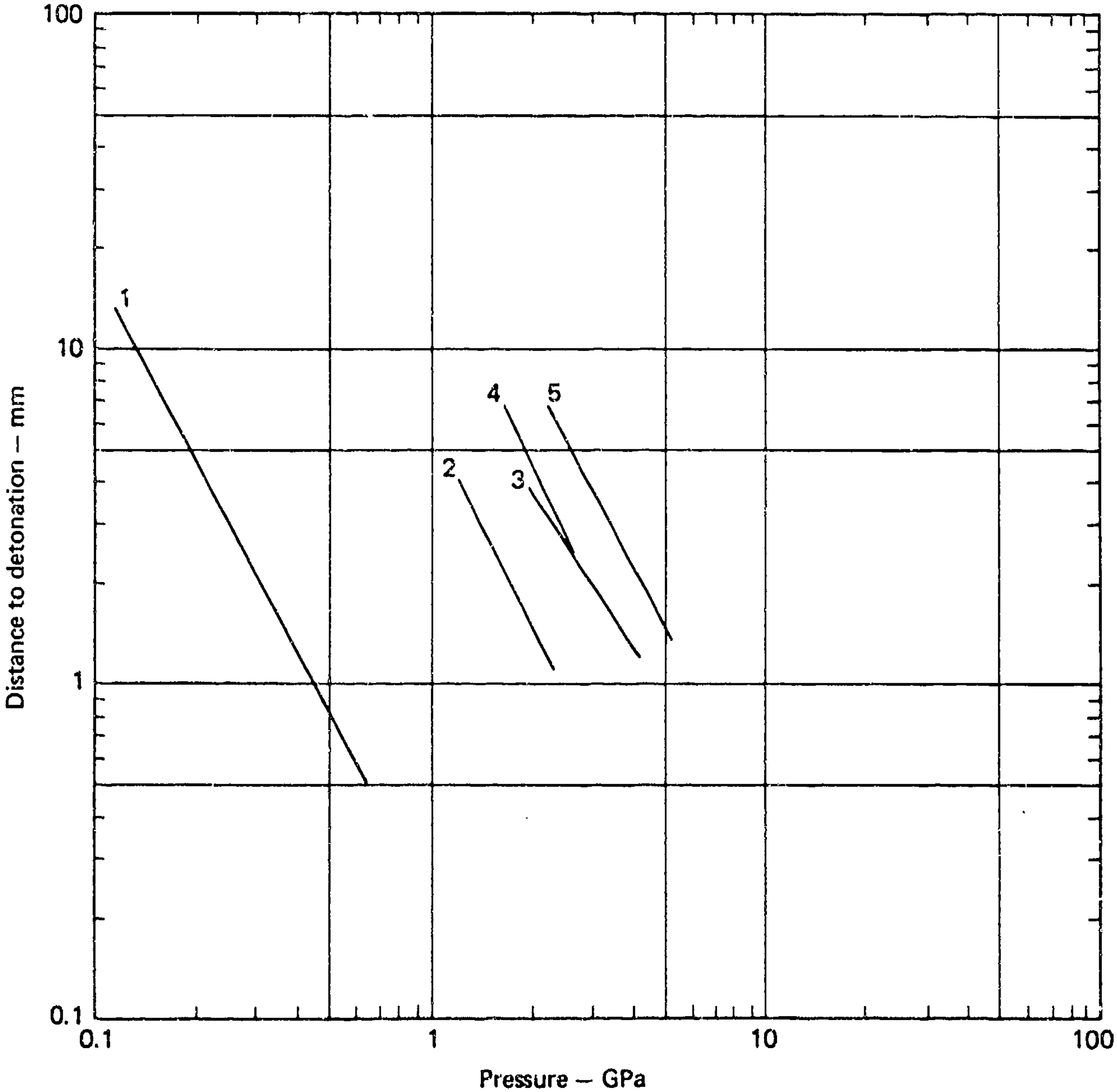


Fig. 9-21b. (Continued)

Fig. 9-21c. Pop plots of insensitive explosives as functions of density, particle size, and temperature.[a]

Curve number	Explosive	Density (ρ) [g/cm^3 (Mg/m^3)]	Particle size	Ref.
1	LX-17	1.90	Coarse	23
2	LX-17	1.81	Coarse	23
3	LX-17	1.92[b]	Coarse	23
4	LX-17	1.88[c]	Coarse	23
5	NQ	1.69		34
6	NQ	1.72	Large grain	37
7	NQ	1.69	Commercial	37
8	PBX-9502	1.90	Standard	37
9	PBX-9502	1.89	Standard	40
10	TATB	1.84	Med. coarse	23
11	TATB	1.88	Purified	37
12	TATB	1.81	Micronized	37
13	TATB	1.81	Superfine	37

[a] Temperature is ambient unless noted otherwise.
[b] -44°C.
[c] 68°C.

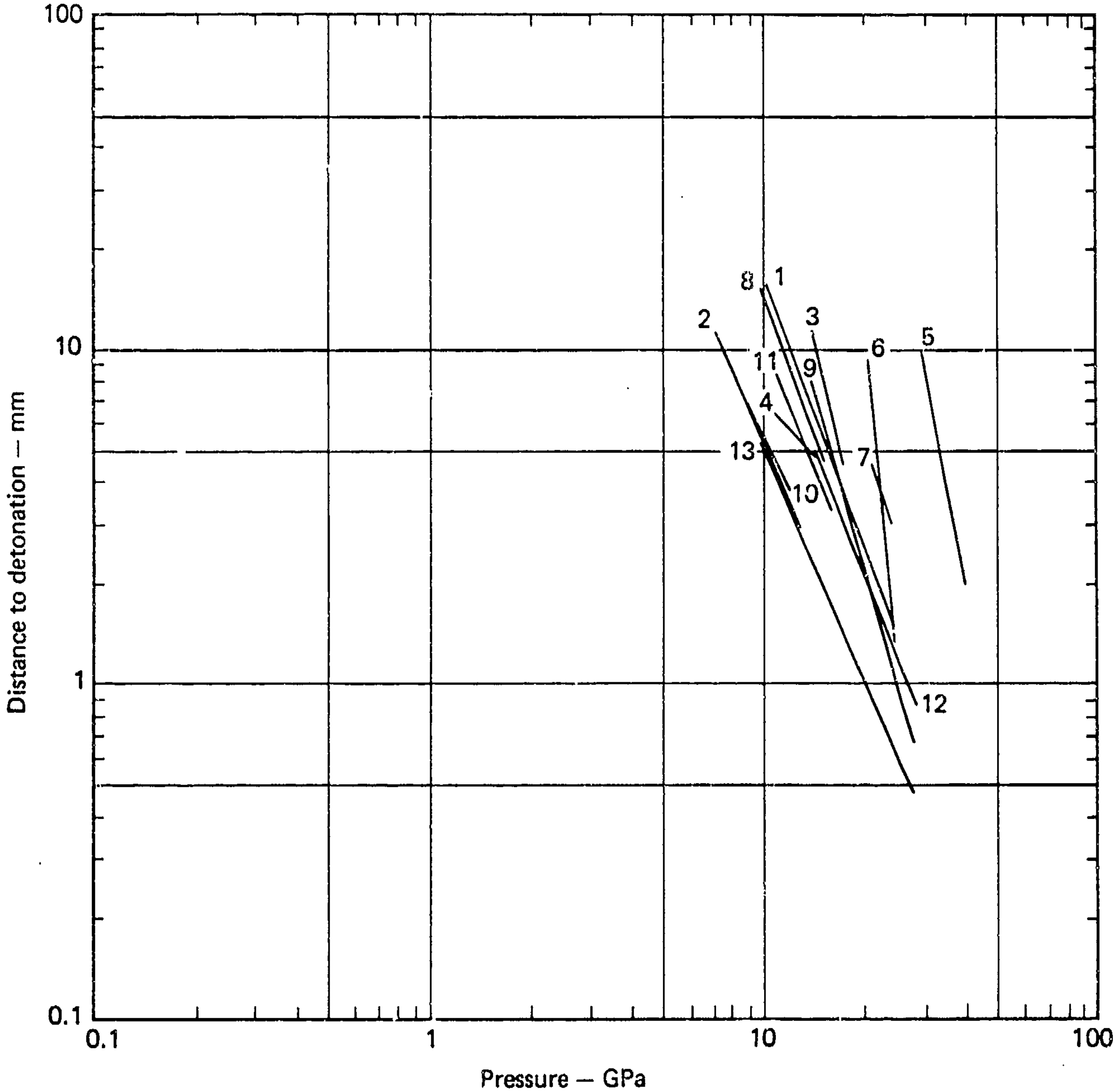


Fig. 9-21c. (Continued)

Fig. 9-21d. Pop plots of HMX and HMX-based explosives.

Curve number	Explosive	Density (ρ) [g/cm^3 (Mg/m^3)]	Ref.
1	HMX	1.89	37
2	LX-04-1	1.86	41
3	LX-07-2	1.86	42
4	LX-09-0	1.84	41
5	LX-10-0	1.86	42
6	PBX-9011	1.79	37
7	PBX-9404	1.72	37
8	PBX-9404	1.84	37
9	PBX-9501	1.83	37
10	PBX-9501	1.84	41

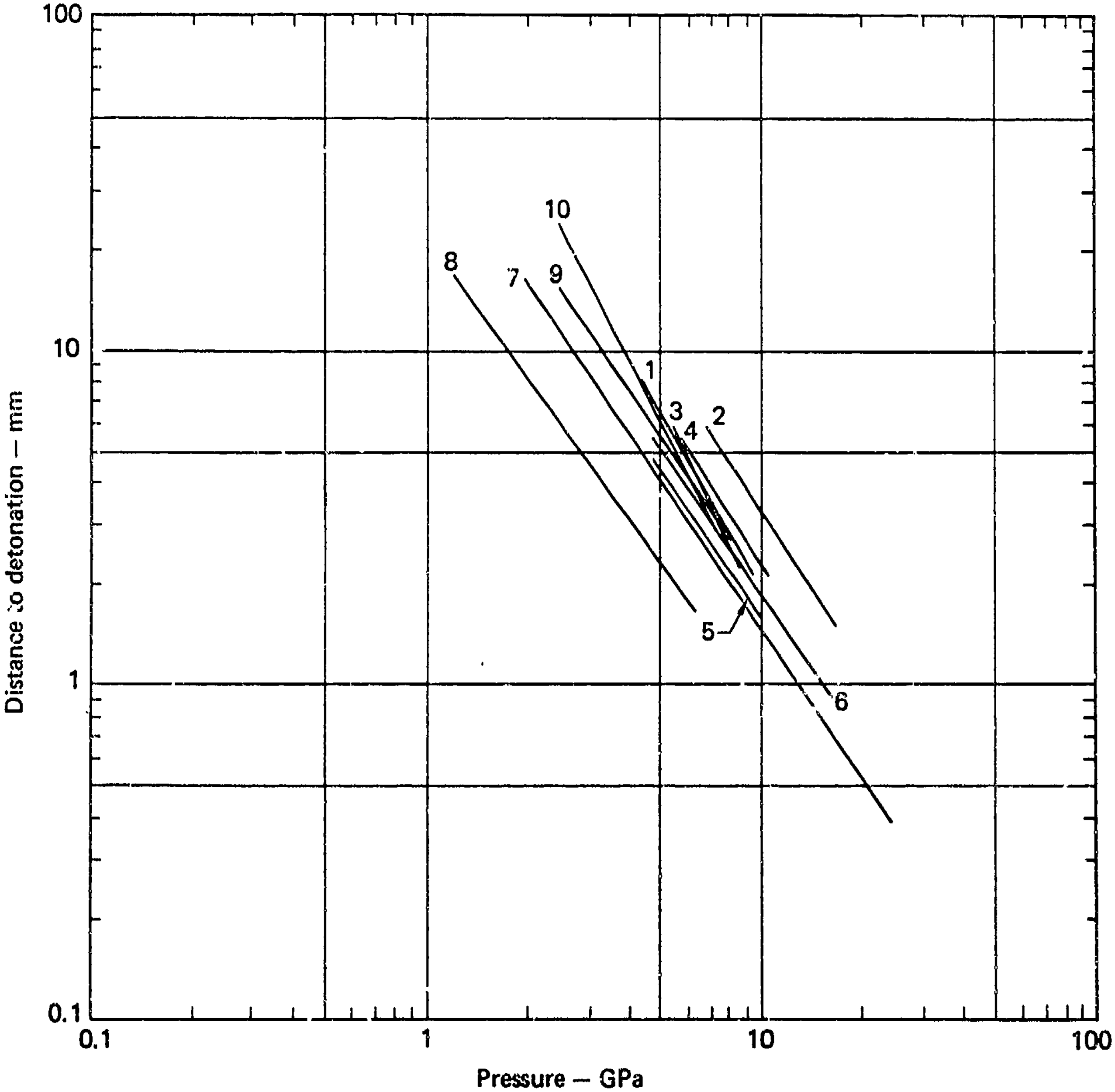


Fig. 9-21d. (Continued)

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10. ELECTRICAL PROPERTIES

Like other polymeric materials, the secondary HEs discussed here are good electrical insulators. They are not considered sensitive to accidental initiation from electric sparks. Primary explosives are more easily initiated by accidental electrical stimuli. Table 10-1 lists the highest electrostatic-discharge energies tolerated by an explosive at 5000 V without ignition.

Table 10-1. Highest electrostatic-discharge energy at 5000 V for zero ignition probability of explosives.[1]

Explosive	Energy (J)		Type of ignition	
	Unconfined	Confined	Unconfined	Confined
Black powder[a]	>12.5	0.8	None	Deflagration
Explosive D[b]	>12.5	6.0	None	Detonation
[a]	0.025	6.0	Deflagration	Detonation
Lead azide	0.0070	0.0070	Detonation	Detonation
Lead styphnate	0.0009	0.0009	Detonation	Detonation
NC (13.4% N)	0.061	3.1	Deflagration	Deflagration
NG (25°C)	>12.5	0.90	None	Detonation
PETN[b]	>11.0	0.21	None	Detonation
[a]	0.062	0.21	Deflagration	Detonation
Tetryl[b]	>11.0	4.68	None	Detonation
[a]	0.007	4.38	Deflagration	Detonation
TNT[b]	>11.0	4.68	None	Detonation
[a]	0.062	4.38	Deflagration	Detonation

[a] Through 100 mesh.
[b] As received.

10.1 DIELECTRIC CONSTANT

The dielectric constant (ϵ), also called relative permittivity, is density- and temperature-dependent; it is defined as the ratio of the capacitance of a condenser filled with the sample material to the capacitance of the condenser having a vacuum between its plates. Table 10-2 gives the dielectric constants of several explosives.

An empirical, logarithmic relationship has been established for two-component HEs composed of the same materials in different proportions.[2] Figure 10-1 illustrates this mixing rule for TNT/RDX compositions. The relationship is expressed as:

$$\log \epsilon_t = \theta_1 \log \epsilon_1 + \theta_2 \log \epsilon_2,$$

where

ϵ_t = relative permittivity of the mixture,
ϵ_1, ϵ_2 = relative permittivities of components,
θ_1, θ_2 = volume ratios of components.

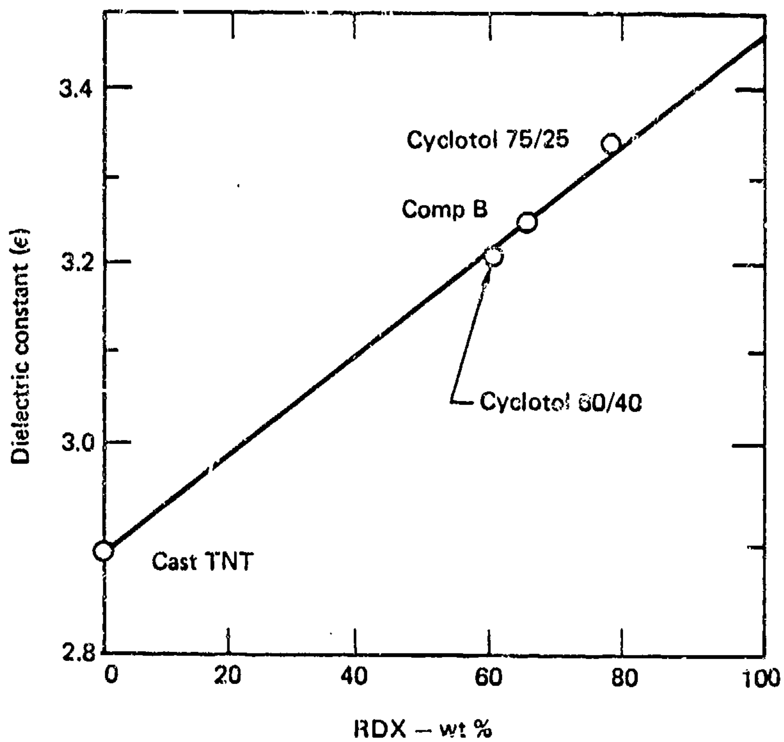


Fig. 10-1. Logarithmic mixing rule applied to TNT/RDX mixtures.[2]

Table 10-2. Dielectric constant, ε, at room temperature.

	Density, ρ [g/cm³ (Mg/m³)]									
Material	0-0.99	1.0-1.19	1.2-1.39	1.4-1.59	1.6-1.79	1.8-1.99	2.0-2.19	2.2-2.39	2.4-2.59	<4	R
AN					~7.1[a]						3
Baratol									4.12[b]		2
Boracitol				2.84[b]							2
Comp B					3.25[b]						2
Comp B-3 (pressed)					3.41[c]						4
Cyclotol 75/25					3.38[b]						2,5
FPC 461					2.82[d]						6,7
HMX-I(β)						3.087[e]					8
HMX-II(α)						4.671[e]					8
HMX-III(γ)						3.867[e]					8
Kel-F							3.00[d]				9
Lead azide											15
(a axis)										17[f]	
(b axis)										120[f]	
(c axis)										40[f]	
LX-04-1						3.44[c]					4

Table 10-2. Dielectric constant (ε) at room temperature. (Continued)

	Density, ρ [g/cm³ (Mg/m³)]										
Material	0-0.99	1.0-1.19	1.2-1.39	1.4-1.59	1.6-1.79	1.8-1.99	2.0-2.19	2.2-2.39	2.4-2.59	<4	Ref.
Octol						3.20[e]					2
PBX-9404 (pressed)						3.52[c]					4
PETN	2.102[g]	2.310[g]		2.447[g] 2.577[g]	2.727[g] 2.897[g]						2,6,7
PETN (detonator grade)					2.95[c] 3.5[d]						4 2,5
Picric acid					3.59						16
Polystyrene		2.49-2.55[d] 2.61[d]									10,11
RDX					3.14[d]						12
Sylgard		2.77[b]									10,11
Tetryl	2.059[g]	2.163[g]		2.728[g] 2.905[g]	3.097[g] 3.304[g]						2,6

Table 10-2. Dielectric constant (ε) at room temperature. (Continued)

Material	Density, ρ [g/cm³ (Mg/m³)] 0-0.99	1.0-1.19	1.2-1.39	1.4-1.59	1.6-1.79	1.8-1.99	2.0-2.19	2.2-2.39	2.4-2.59	<4	Ref.
TNT (cryst.)	2.048[g]	2.131[g]		2.629[g] 2.795[g]							6
(cast)					2.88[e]						2,6
(a axis)					2.564[h]						13
(b axis)					2.347[h]						13
(c axis)					2.083[h]						13
Viton A						10.5[d]					14

[a] Measured at 9.52 GHz.
[b] Measured at 3 GHz.
[c] Measured at 25 GHz.
[d] Measured at 1 kHz.
[e] Measured at 5 MHz.
[f] Measured at 10^2–10^6 Hz.
[g] Measured at 35 GHz.
[h] Measured at 10 kHz.

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11. TOXICITY

Toxic reactions can result from exposure to some HEs and components by inhalation of the dust or vapor, by ingestion, or by contact with the skin. Most explosives are not highly toxic, but careless handling can result in systemic poisoning, usually affecting the bone marrow (blood-cell-producing system) and the liver.

The following general precautions (LLNL standard operating procedures) should be observed on all HEs:

1. The material should be handled only in a well-ventilated area.
2. Skin contact should be avoided. Explosives can be absorbed through the skin, or they may cause skin rash (which is the most common symptom among explosives handlers). Daily baths and changes of clothing are recommended for persons engaged in HE processing.

Toxicities, when known, are listed in Table 11-1. The toxicities of mixtures are like those of their components.

Table 11-1. Health hazards of explosives and binders.

Material	Degree of toxicity	Ref.	Material	Degree of toxicity	Ref.
AN	Low	6	HMX	Low	6
AP	Low	6	HNAB	Low	12
BDNP-F	None	1	HNS	Low	12
BTF	Low	16	Lead azide	High	6
Cab-O-Sil	Low	2	NC	None	6
CEF	Moderate when ingested	3	NG	High	6
			NM	Moderate	6
Comp C-4	Moderate	4	NQ	High	6
DATB	Low	14	PETN	High	6,15
DEGN	Moderate	5	Picric acid	Moderate	9
DIPAM	Moderate	6	RDX	Low	13,15
DOP	Low	7	TATB	Low	14
Estane	None	8	Tetryl	High	6,15
Explosive D	Moderate	9	TNM	Very high	6
FEFO	High	10	TNT	Moderate	6
FPC 461	Low	11			

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12. INTRODUCTION

A series of mock materials has been formulated that duplicate compositional, mechanical, or other properties of HEs but lack their hazards. These explosive simulants have proven convenient for test purposes because of their relative insensitivity. Characteristics and properties of these mocks are summarized in this section according to the same scheme used for HEs in the preceding section.

A mock HE is a nonexplosive equivalent of a particular explosive formulation. The approved all-purpose mock for LX-04-1 might be called LM-04-1 at LLNL. However, mocks seldom pair in one-to-one relation with the corresponding HE. For PBX-9404, for example, there are three separate mocks: a compositional mock, a physical-property mock, and a thermal mock. For this and other reasons too involved to explain here, no attempt is made to achieve correspondence beyond the class designation.

Selection of the best mock HE for a specific purpose involves the following steps:

- Selection of the properties to be mocked. Some examples are:
  1. Atomic composition.
  2. Density.
  3. Thermal properties.
     a. Coefficient of thermal expansion.
     b. Heat transfer properties (see Section 15).
  4. Mechanical properties.
     a. Elastic behavior.
     b. Viscoelastic behavior.
     c. Failure behavior.
- Comparison with the HE of interest over the appropriate temperature range. This may be done either by direct comparison of properties or by comparison of results from analytical calculations.

13. MOCK EXPLOSIVES - NAMES AND FORMULATIONS

Formulations of mock explosives contain about 0.05% of a red pigment that uniquely identifies them as a class of materials. Table 13-1 lists their compositions.

Table 13-1. Formulations of mock explosives.

Mock HE	Explosive and properties mocked	Composition, wt%	
900-10	PBX-9404: mechanical properties	Pentaerythritol	48.0
		$Ba(NO_3)_2$	46.0
		NC	2.8
		CEF	3.2
900-15	PBX-9501: thermal properties	$Ba(NO_3)_2$	84.5
		Polystyrene	11.6
		DOP	3.9
900-19	PBX-9502	Cyanuric acid	95
		Kel-F 800	5
905-03	PBX-9404 and LX-10: atomic composition	Cyanuric acid	60
		Melamine	32
		NC	4
		CEF	4
LM-04-0	LX-04: atomic composition[a]	Cyanuric acid	59.7
		Melamine	23.5
		Viton A	16.8
RM-04-BG	LX-04: mechanical properties--static and dynamic	Cyanuric acid	70.5
		$Ba(NO_3)_2$	14.5
		Viton A	15

[a] Although designed as an atomic-composition mock, LM-04-0 can also be used as an approximate mock of the mechanical properties of LX-04-1 at ambient conditions.

14. MOCK EXPLOSIVES - PHYSICAL PROPERTIES

Table 14-1 gives the densities and elemental compositions of mock explosives.

Table 14-1. Physical states, densities, and atomic compositions of mock HEs.

		Density, ρ		Elemental composition[a]				
		TMD	Nominal density					
Mock HE	Physical state	[g/cm^3 (Mg/m^3)]	[g/cm^3 (Mg/m^3)]	C	H	N	O	Other
900-10	Solid	1.89	1.88	1.89	4.44	0.38	2.62	Ba 0.18 Cl 0.03 P 0.01
900-15	Solid	--	--	2.30	2.23	2.21	2.21	Cl 0.04 F 0.13
900-19	Solid	--	1.64	2.32	3.18	2.96	1.60	Cl 0.04 P 0.01
905-03	Solid	1.66	1.60	1.13	1.27	0.65	1.98	Ba 0.32
LM-04-0	Solid	1.727	1.70	2.34	2.66	2.51	1.39	F 0.63
RM-04-BG	Solid	1.914	1.87	2.02	1.86	1.75	1.97	Ba 0.06 F 0.54

[a] Molecular weights of these mixtures are arbitrarily taken as 100.

15. THERMAL PROPERTIES

This section contains information on the selection of heat transfer properties, thermal conductivities (λ), coefficients of thermal expansion (CTE), glass transition points (T_g), specific heats (C_p), and indications of thermal stability (DTA).

Table 15-1 shows how to select the appropriate heat-transfer properties to be simulated. This table is based on mocking the temperature under specific conditions. In steady-state problems with insulated or prescribed-temperature boundary conditions, thermal properties have no significance and any material could be used.

Table 15-1. Criteria for selection of heat-transfer properties to be mocked.

Boundary conditions	Transient problems[a]	Steady-state problems[a]
No heat generation		
Insulated	α	-
Prescribed temperature	α	-
Prescribed heat flux	α,λ	λ
Convection	α,λ	λ
Heat generation		
Insulated	α,λ	λ
Prescribed temperature	α,λ	λ
Prescribed heat flux	α,λ	λ
Convection	α,λ	λ

[a] Here λ = thermal conductivity, $\alpha = \lambda/\rho$.

15.1. THERMAL CONDUCTIVITY AND SPECIFIC HEAT

Specific heats were determined by an ice calorimetric technique. Table 15-2 gives the data; Figs. 15-1 and 15-2 show thermal conductivity and specific heat as functions of temperature.

Table 15-2. Thermal conductivities (λ)[1] and specific heats (C_p).[2]

	λ			C_p	
Mock HE	Btu/hr-ft-°F	(10^{-4} cal/cm-sec°C)	(W/m-K)[a]	[Btu/lb-°F, cal/g-°C]	(kJ/kg-K)[b]
900-10	0.31	(12.8)	(0.54)	0.23	(0.96)
900-15	--	10.8	(0.45)	--	--
900-19	--	24.9	(1.04)	--	--
905-03	0.36	(14.9)	(0.62)	0.29	(1.21)
LM-04-0	0.59	(24.3)	(1.02)	0.28	(1.17)
RM-04-BG	0.66	(27.2)	(1.14)	0.24	(1.004)

[a] One cal/cm-sec-°C = 4.184 x 10^2 W/m-K; 1 Btu/hr-ft-°F = 0.00414 cal/cm-sec-°C = 1.73 W/m-K.
[b] One Btu/lb-°F = 1 cal/g-°C = 4.184 kJ/kg-K.

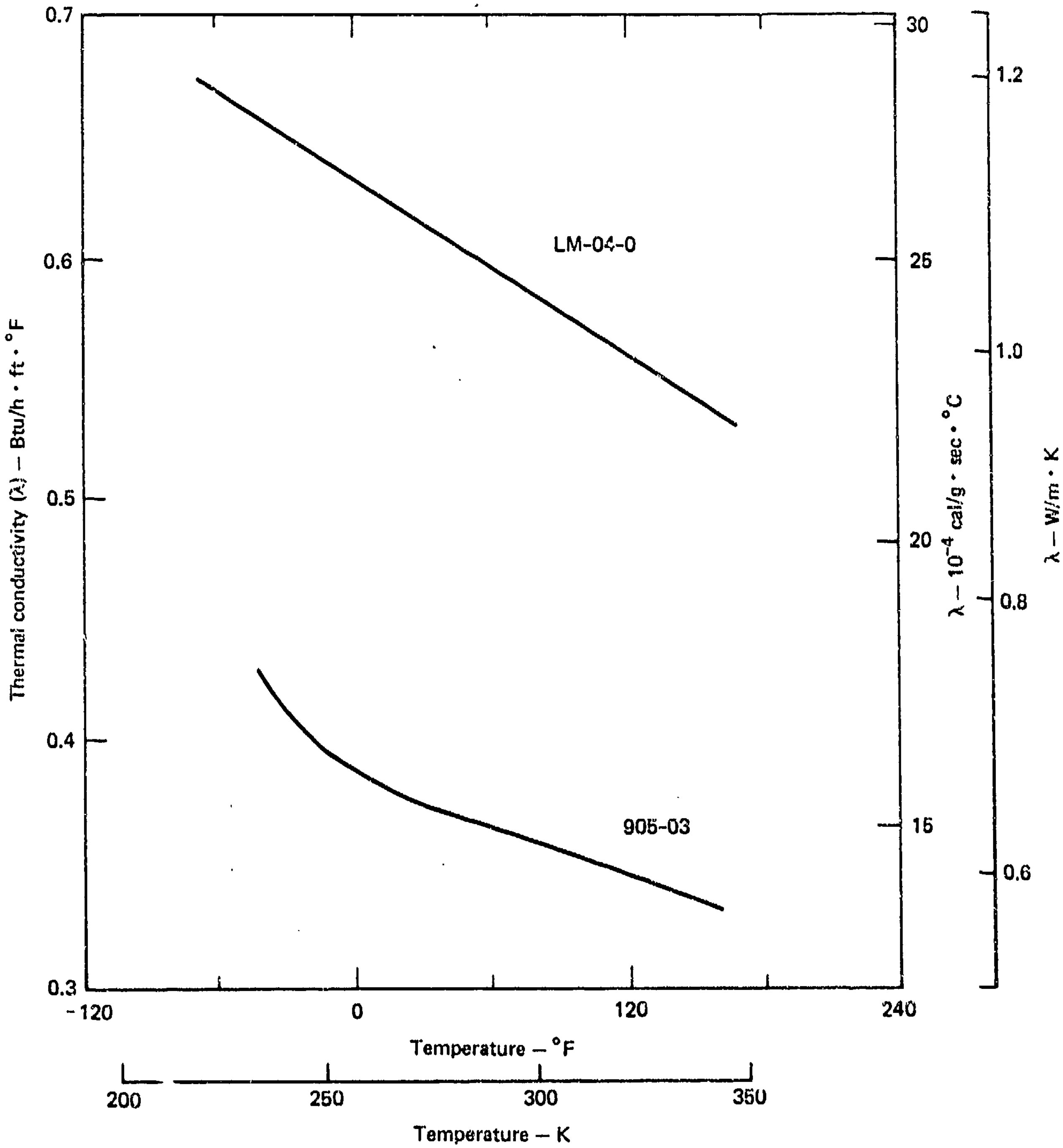


Fig. 15-1. Thermal conductivity (λ) of LM-04-0 and 905-03 as a function of temperature. Conversion factors: 1 Btu/hr-ft-°F = 1.73 W/m-K; 1 cal/cm-sec-°C = 4.184 x 10^2 W/m-K.

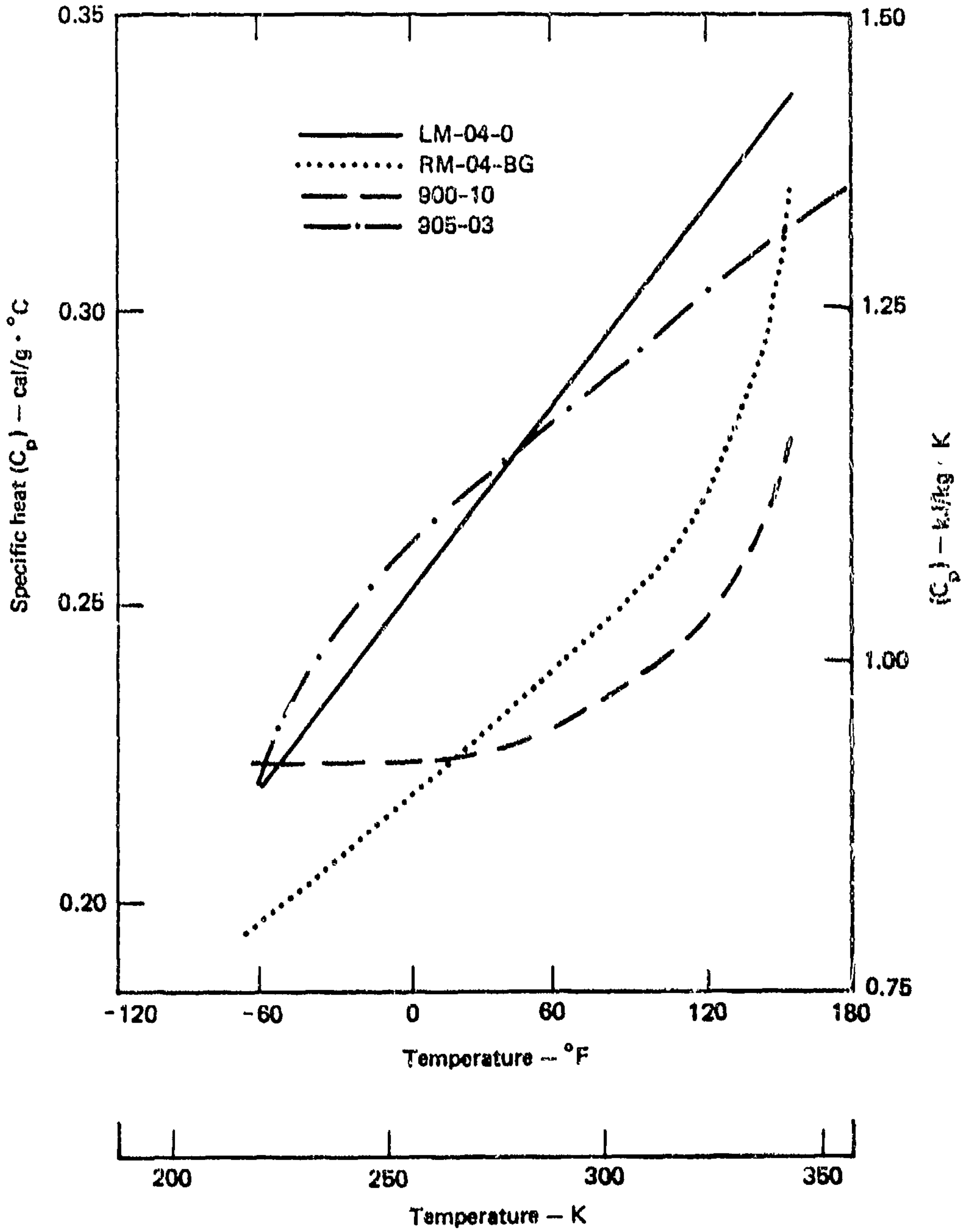


Fig. 15-2. Specific heat (C_p) of mock HEs as a function of temperature. Conversion factors: 1 Btu/hr-ft-°F = 1.73 W/m-K; 1 cal/cm-sec-°C = 4.184 x 10^2 W/m-K.

15.2. THERMAL EXPANSION

Early CTE data for cyanuric acid-type mock HEs were affected by surface chalking and growth; this is now prevented by a Parylene coating. CTE data are given in Table 15-3.

Table 15-3. Coefficients of thermal expansion (CTE)[a,3] and glass transition temperatures (T_g).

Mock HE	Linear CTE (α) 10^{-6} in./in.-°F	Linear CTE (α) [10^{-6} cm/cm-°C (μm/m-K)]	Temperature °F	Temperature (K)
900-10	15.5	(27.9)	-65 to -30	(219-239)
	23.3	(41.9)	-10 to 165	(250-347)
905-03	20.8	(37.4)	-65 to -10	(219-250)
	29.5	(53.1)	10 to 165	(261-347)
LM-04-0	2[illegible].5	(38.7)	-65 to -24	(219-243)
	43.9	(79.0)	10 to 165	(261-347)
RM-04-BG	19.2	(34.6)	-65 to -20	(219-244)
	37.5	(67.5)	0 to 165	(255-347)

Mock HE	Cubic CTE (β) [10^{-6} cm/cm-°C (μm/m-K)]	Cubic CTE (β) Temperature °C (K)	T_g °F	T_g (K)	Pressed density ρ [g/cm^3 (Mg/m^3)]
900-10	--	--	-18	(245)	1.880-1.882
905-03	--	--	-18	(245)	1.574-1.589
LM-04-0	--	--	-18	(245)	1.705-1.715
RM-04-BG	199.4 meas.[4] 198 calc.	-30 to 70 (243-343)	-18	(245)	1.80

[a] One in./in.-°F = 1.8 cm/cm-°C = 1.8 m/m-K.

15.3. THERMAL STABILITY

Mock HE 900-10 has been widely used for many years, both at LLNL and at LANL, where it was originally formulated. However, it can be considered a low-grade propellant since it contains a fair amount of $Ba(NO_3)_2$. It burns in air with a sooty flame. Decomposition at 250°C (523 K) results in about 117 ml of gas evolved per gram of material. TIGER calculations were made for approximations of volume burn. The solid products of combustion have not been clearly identified; they could be either $BaCO_3$ or BaO. If we assume that the more energetic $BaCO_3$ is a product, the calculated energy equivalent is about one-third that calculated for TNT. Many differential thermal analyses (DTAs) have been made; they all show a characteristic exotherm (see Fig. 15-3). Mock HE 900-10 is difficult to ignite and does not propagate a detonation, but it is definitely an exothermic material. It is strongly recommended that 900-10 not be used in experiments involving fissile materials.[5]

RM-04-BG contains relatively less $Ba(NO_3)_2$. TIGER calculations for its volume burn indicate that more heat is required to decompose it than is provided by the final oxidation; nevertheless, RM-04-BG does show a small exotherm at 400°C (673 K). Clearly RM-04-BG presents less of a potential hazard than mock 900-10, but it also should not be used for experiments with fissile materials.[5]

The thermal stability of explosive simulants was studied using DTA (see Fig. 15-3).[6]

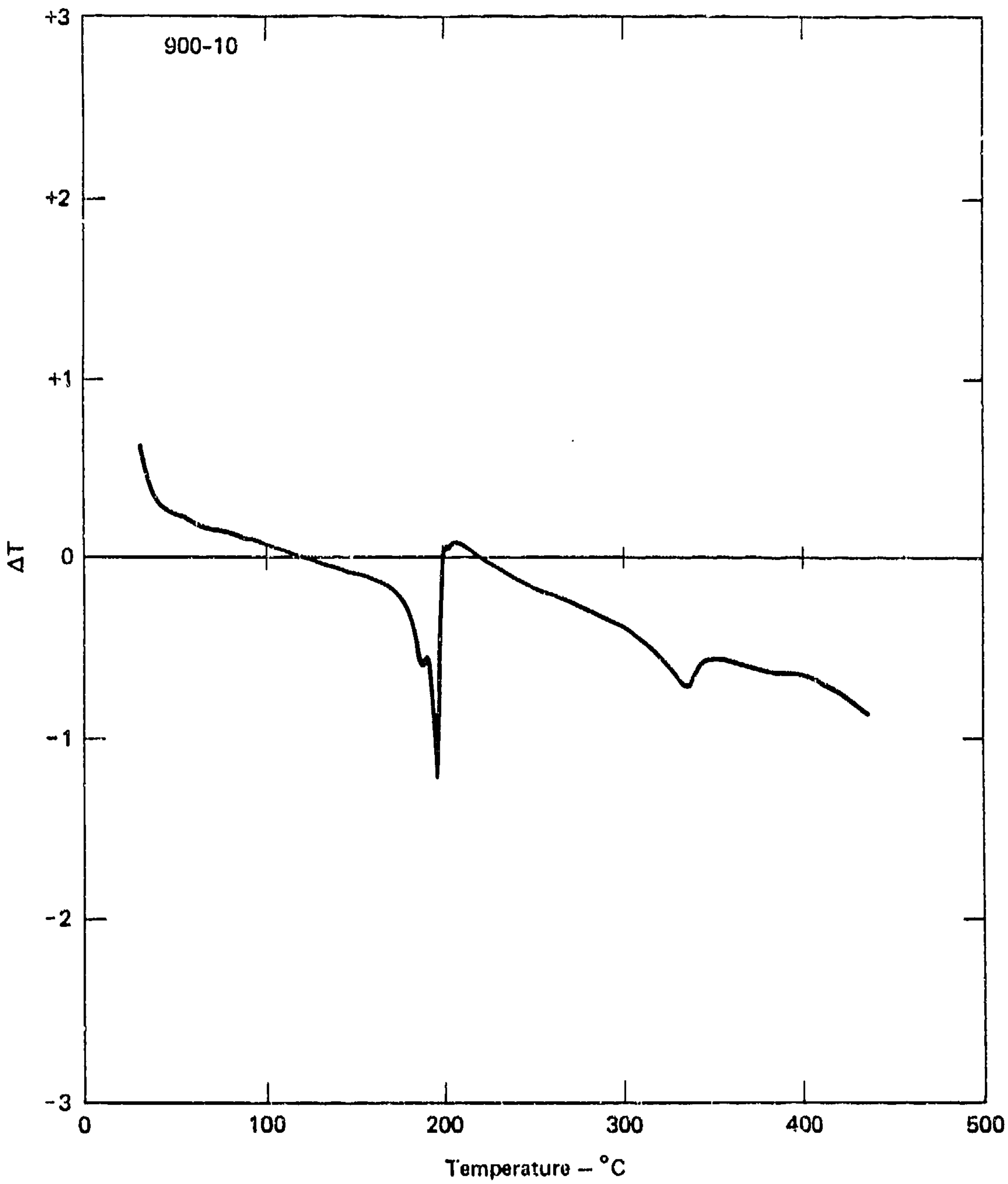


Fig. 15-3a. DTA curve for mock HE 900-10.[46]

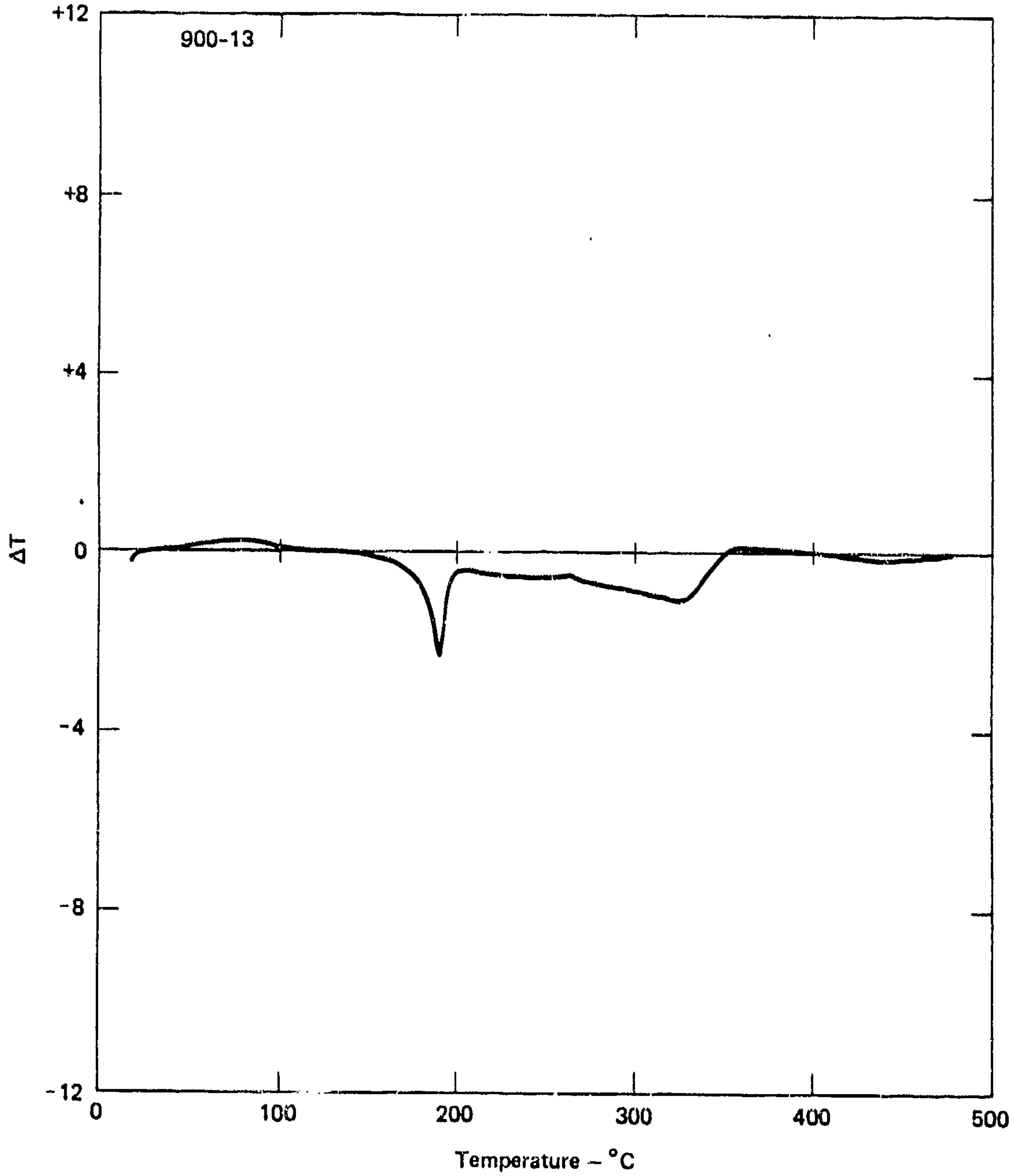


Fig. 15-3b. DTA curve for mock HE 900-13.[46]

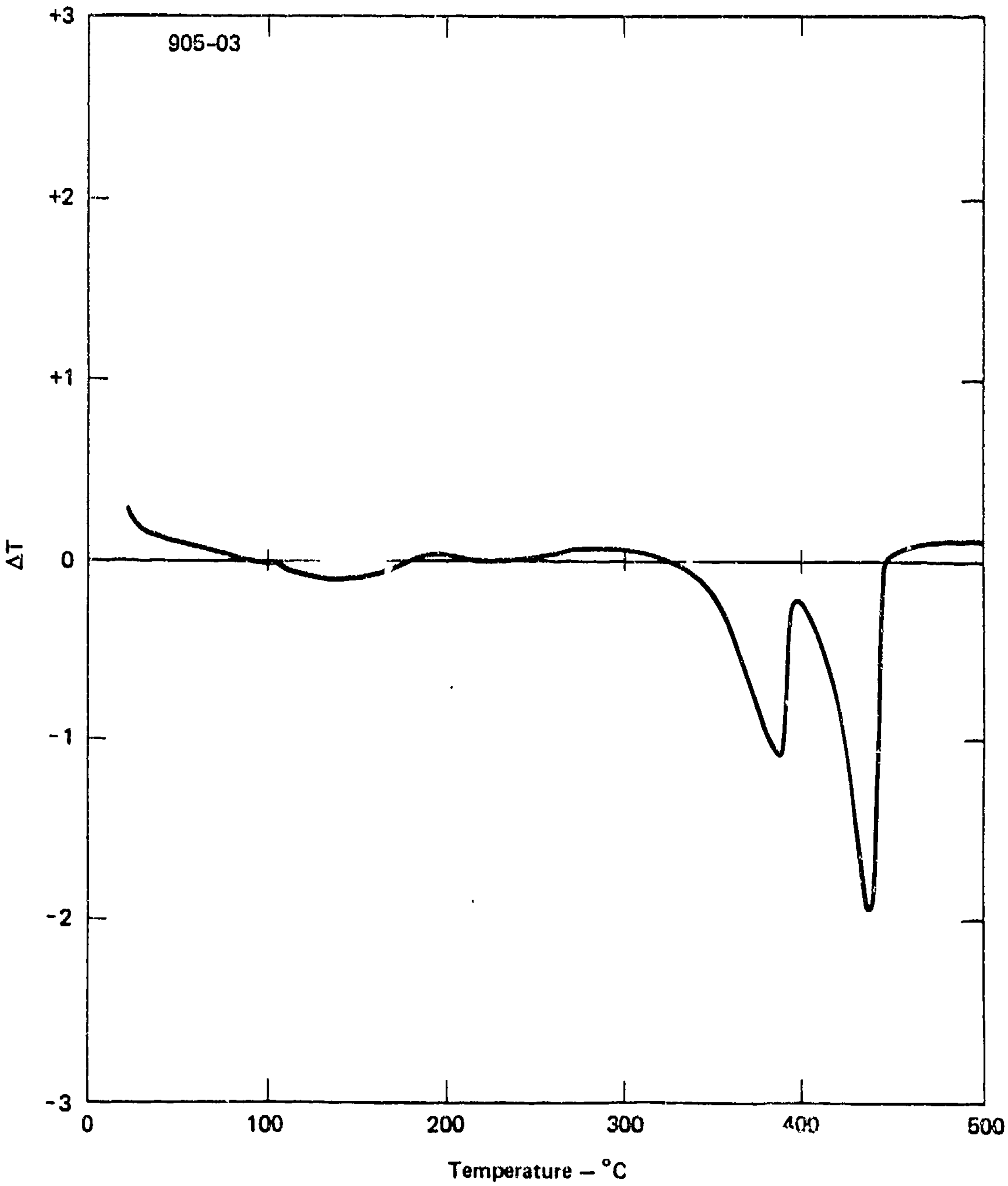


Fig. 15-3c. DTA curve for mock HE 905-03.[46]

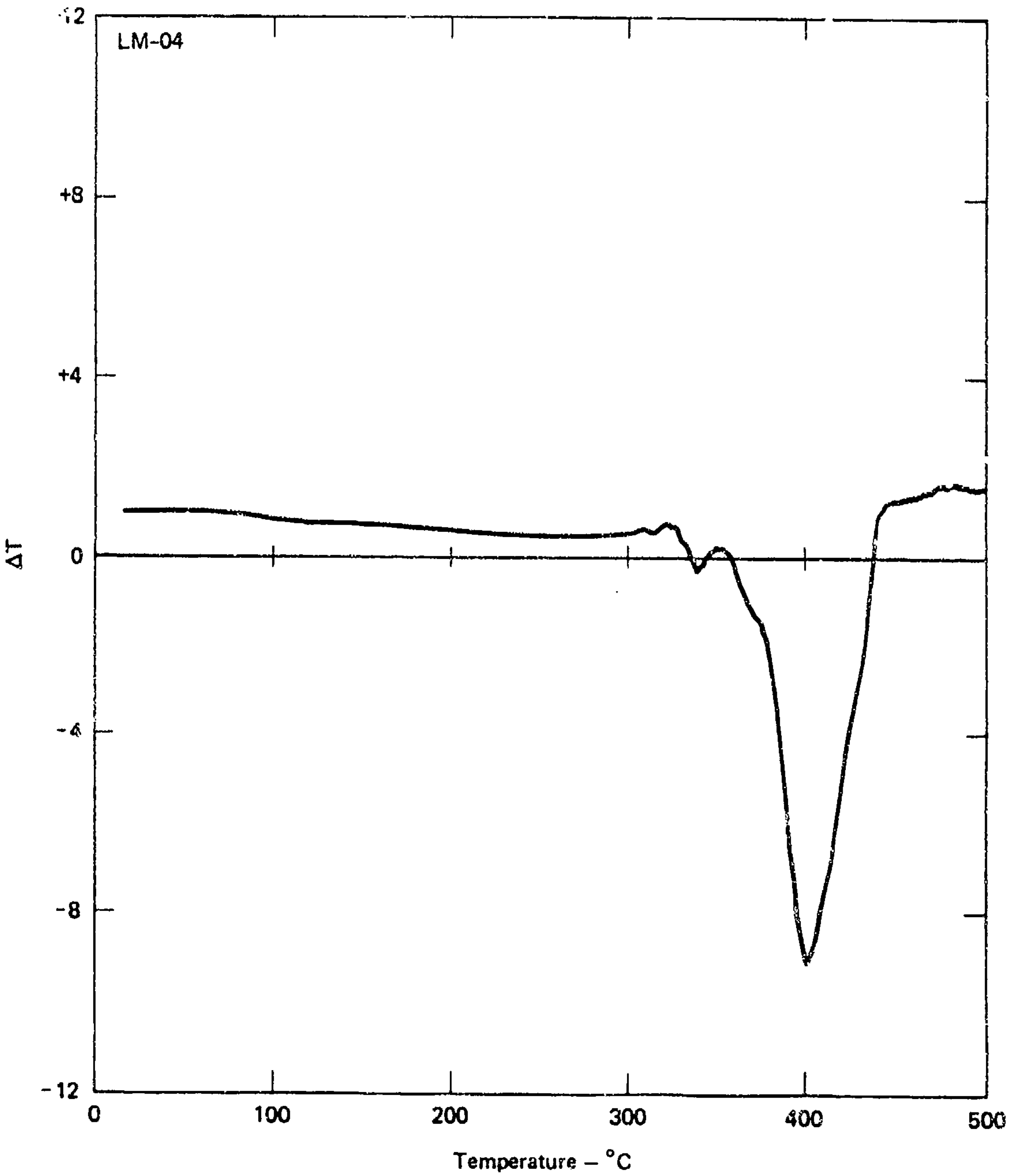


Fig. 15-3d. DTA curve for LM-04.[46]

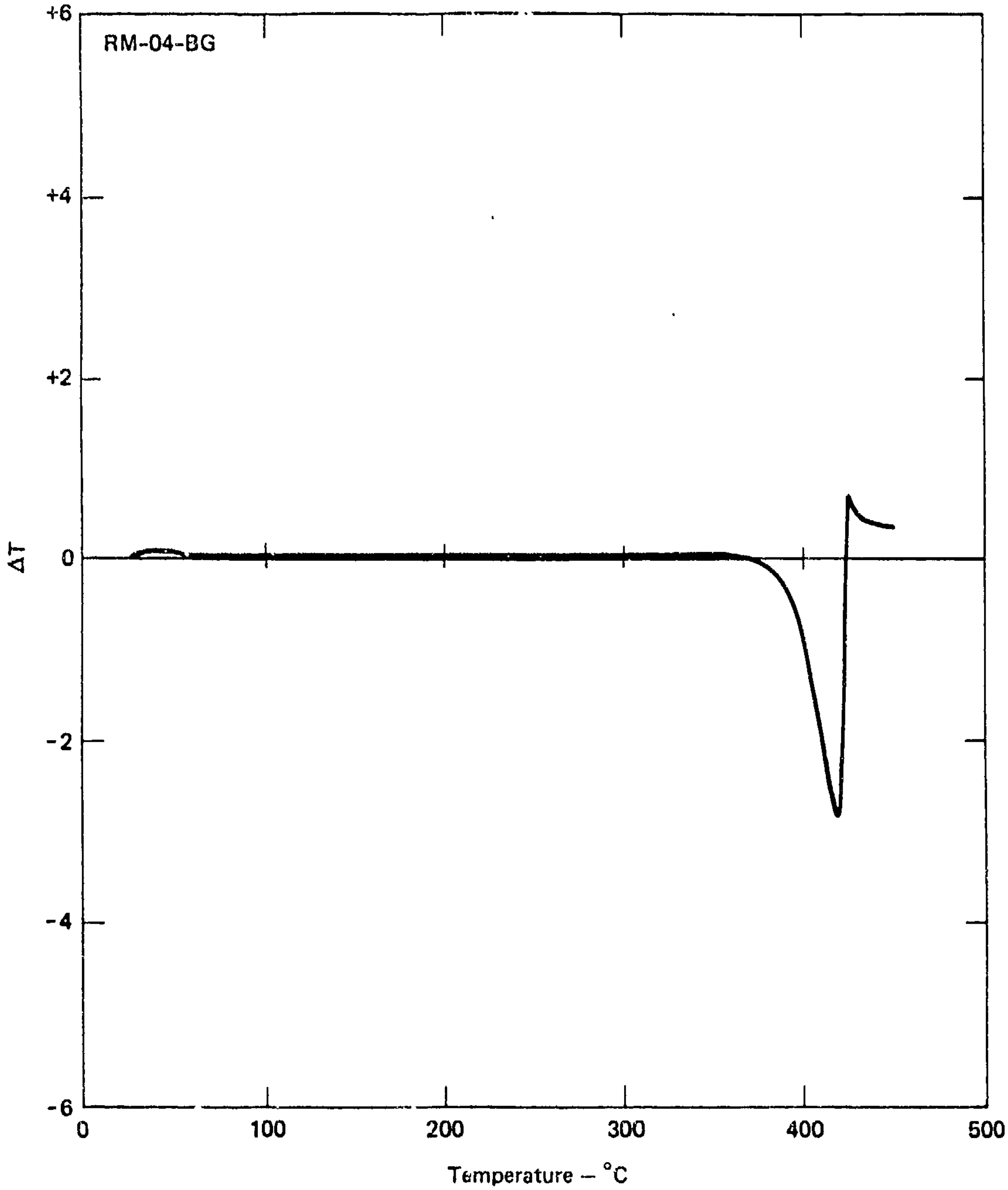


Fig. 15-3e. DTA curve for RM-04-BG.[46]

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16. MECHANICAL PROPERTIES

The data presented here[1] are for each mock HE without comparison with the corresponding live HE. A mechanical mock can best be selected by selecting the appropriate mechanical property to be simulated and then comparing that property with the available data for the HE.

16.1. TIME- AND RATE-DEPENDENT MECHANICAL PROPERTIES

Included here are data on failure envelope, initial modulus (E_0), and tension creep.

16.1.1. Tensile tests

Failure envelope. Figure 16-1 shows failure envelopes of mock HEs at constant strain rate.

Initial uniaxial modulus. Figure 16-2 shows initial uniaxial modulus E_0 vs temperature.

Tensile creep. Figure 16-3 shows tensile creep compliance for explosive simulants at different temperatures at 50 psi (0.345 MPa).

High-strain-rate tensile tests. The Hopkinson split-bar technique was used to determine the compressive stress-strain properties of mock HE and Viton.[3] The results are shown in Fig. 16-4.

16.1.2. Compressive tests

Compressive stress-strain. Figure 16-5 shows uniaxial compression data for RM-04-BG at various strain rates.[2]

Compressive creep. Figure 16-6 shows compressive creep of RM-04-BG at constant strain rate of 0.1 s^{-1} and at ambient temperature.

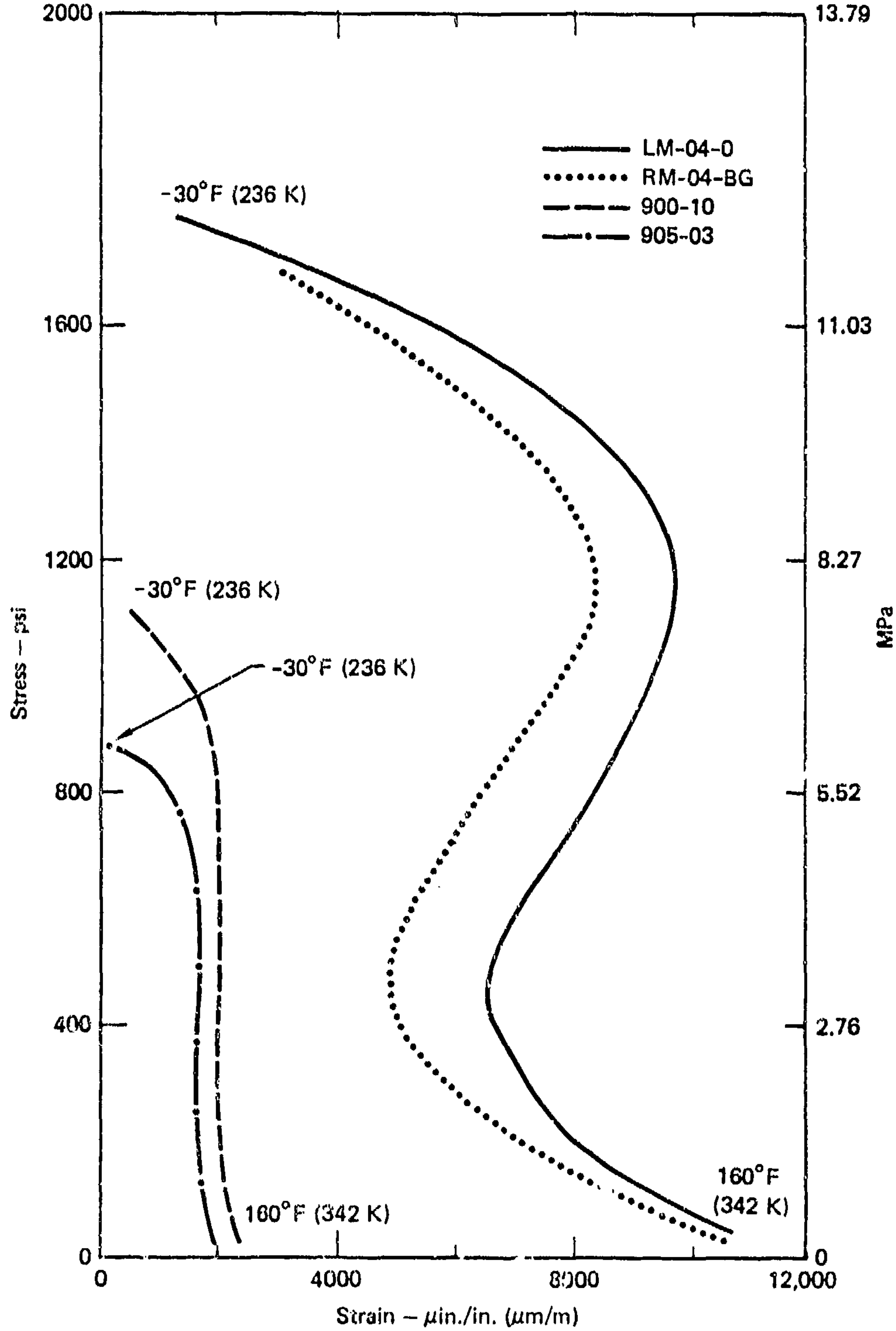


Fig. 16-1. Failure envelopes of mock HEs at constant strain rate ($1.25 \times 10^{-5} s^{-1}$). Conversion factor: 1 psi = 6.895 kPa.

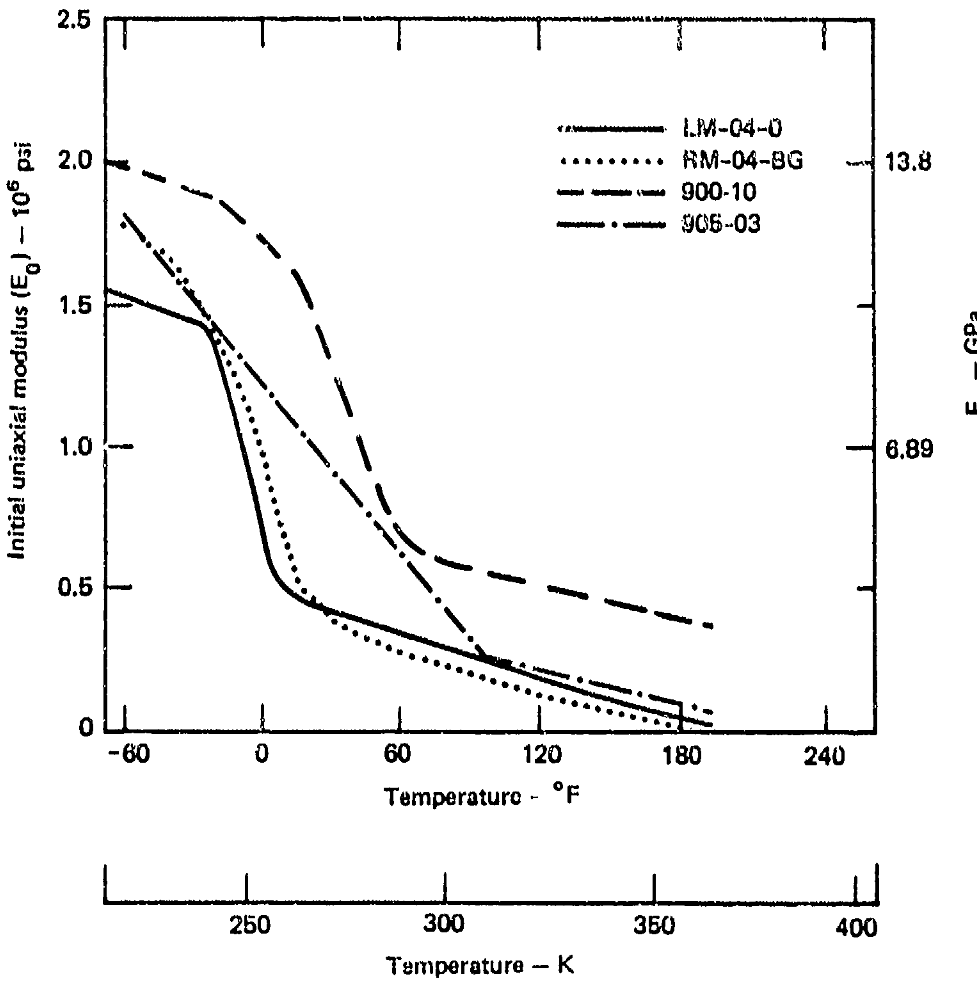


Fig. 16-2. Initial uniaxial modulus E_O vs temperature. Conversion factor: 1 psi = 6.895 kPa.

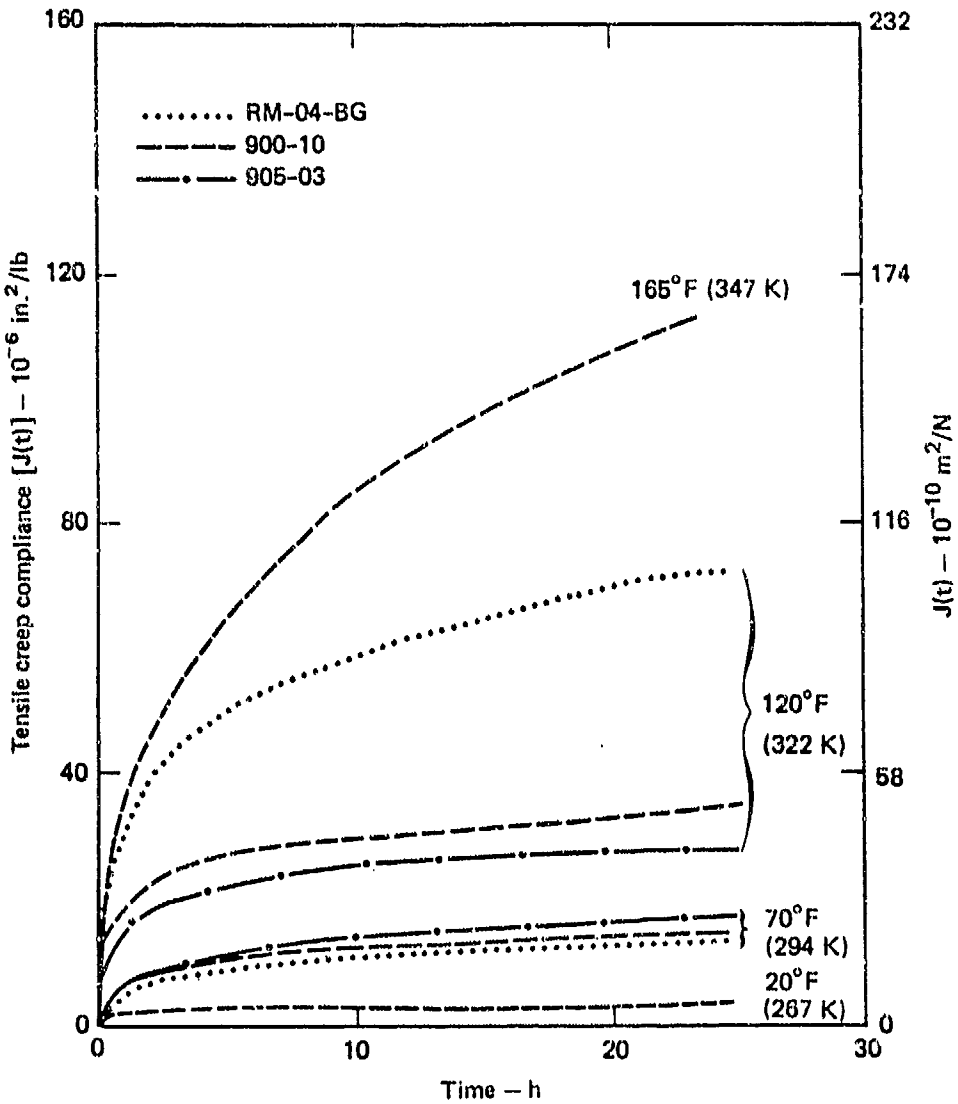


Fig. 16-3. Tensile creep compliance for explosive simulants at different temperatures at 50 psi (0.345 MPa). Conversion factor: 1 $in^2/lbf = 1.45 \times 10^{-4}\ m^2/N$.

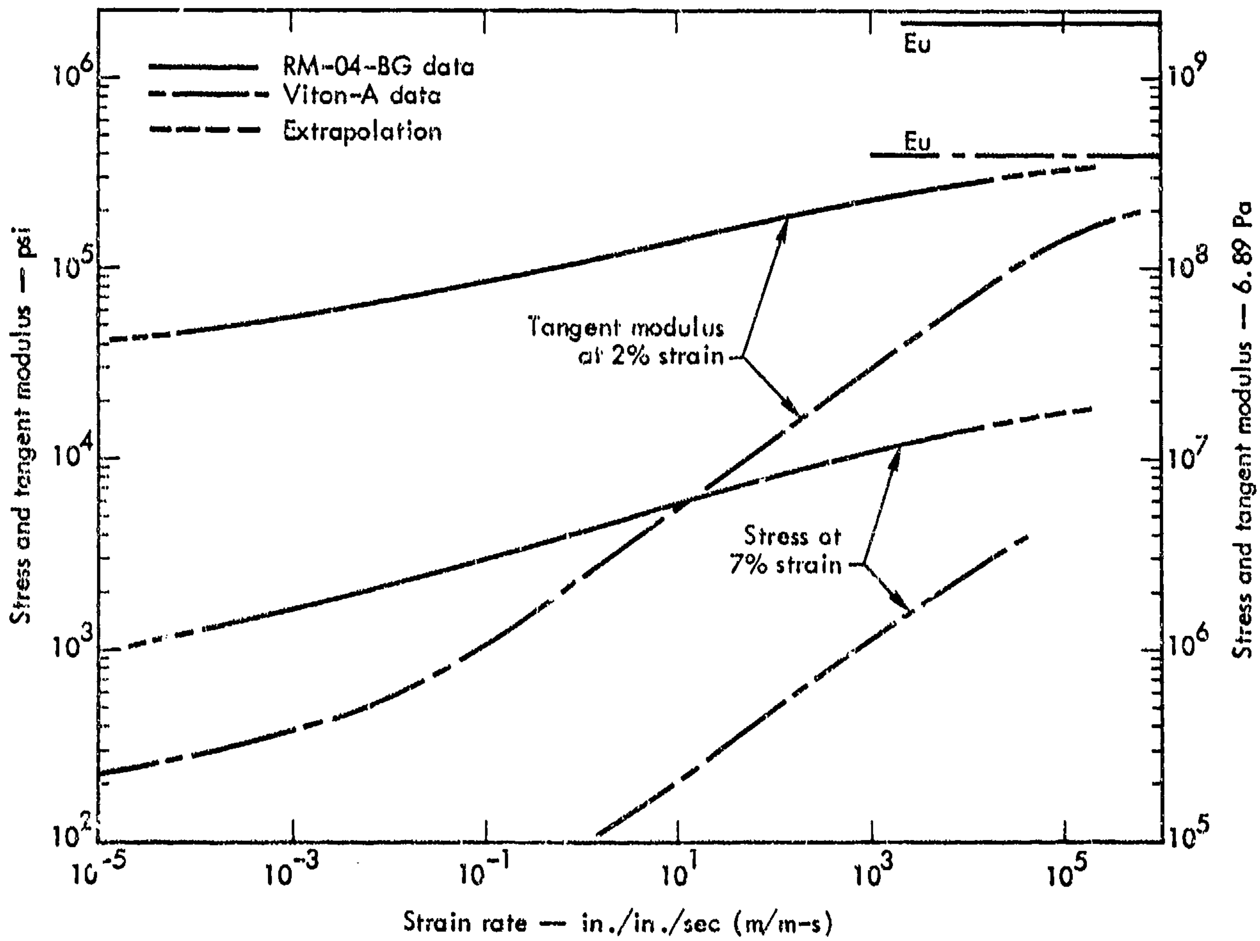


Fig. 16-4. Tensile stress and tangent moduli for RM-04-BG and Viton as a function of strain rate.[2] Also shown is the ultrasonically determined modulus E_u. Conversion factor: 1 psi = 6.895 kPa.

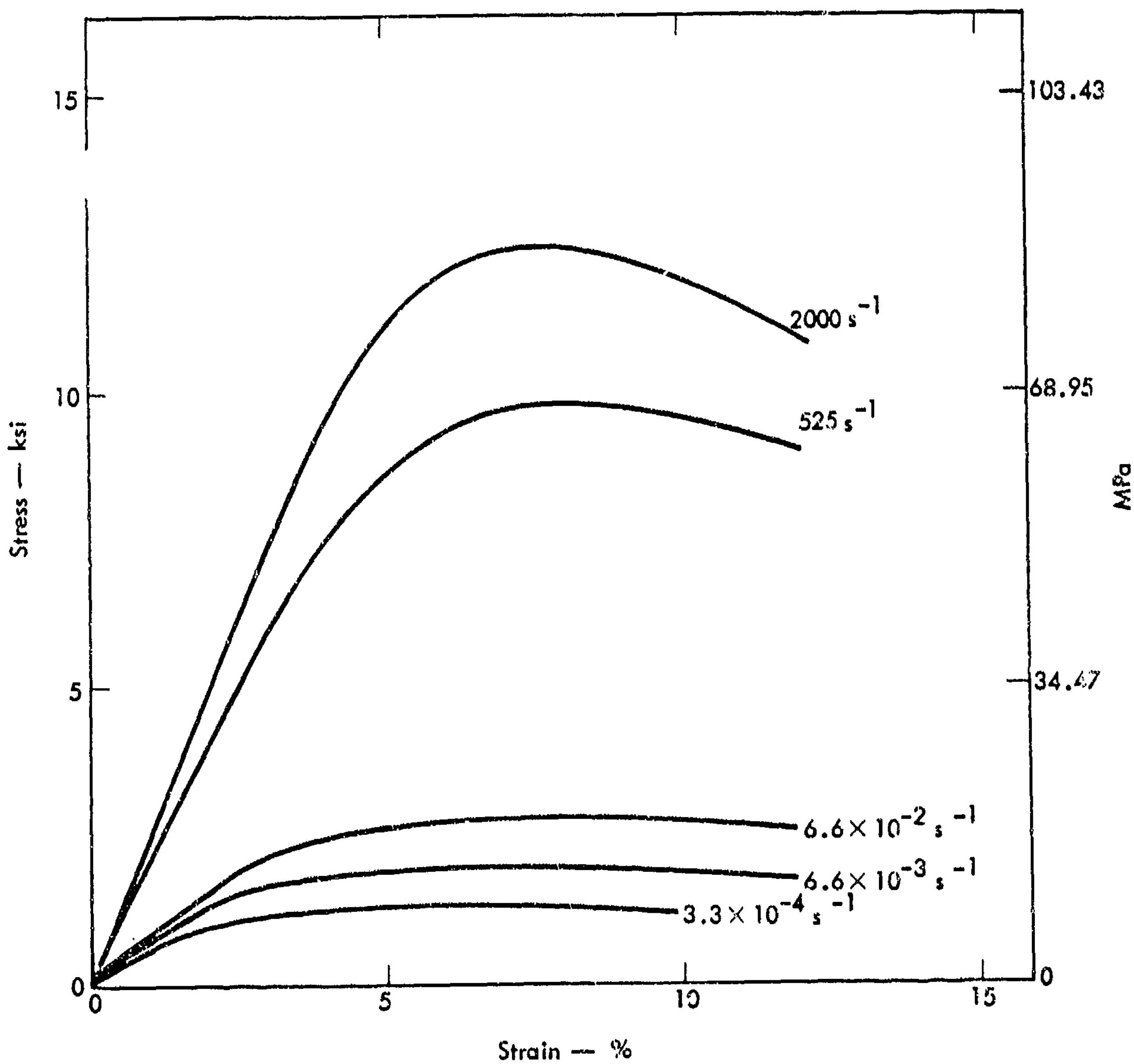


Fig. 16-5. Uniaxial compression data for RM-04-BG at various strain rates at ambient temperature. Conversion factor: 1 psi = 6.895 kPa.

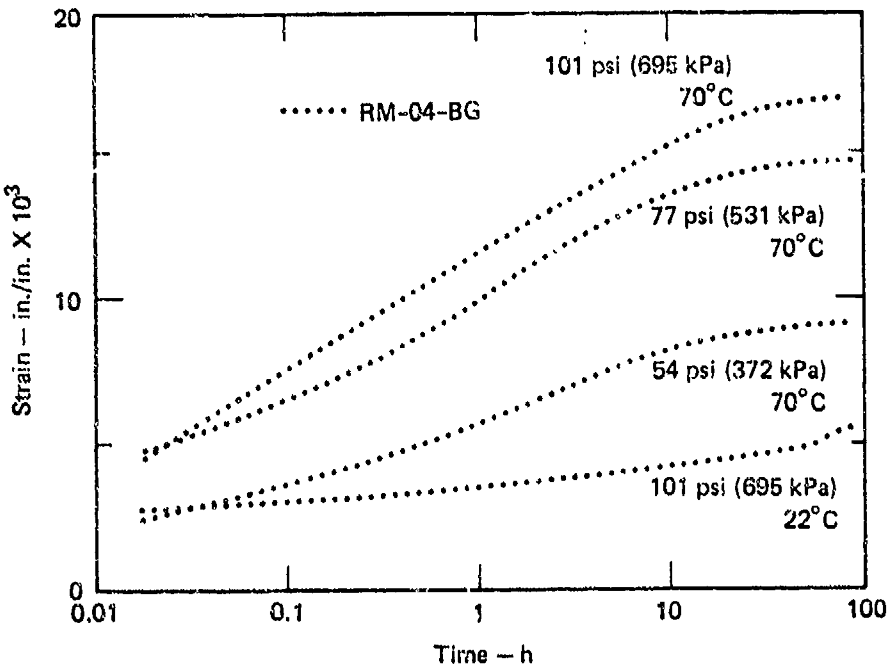


Fig. 16-6. Compressive creep of RM-04-BG at constant strain rate of 0.1 s^{-1}.[4]

16.2. COMPLEX MODULUS PROPERTIES

16.2.1. Complex shear

The components of the complex shear modulus G* (storage modulus G', loss modulus G", and tan δ = G'/G") have been measured with a Rheometric Mechanical Spectrometer (RMS). Results are shown in Fig. 16-7.

16.3. FRICTION

Static coefficients of friction are listed in Table 16-1. The kinematic coefficient of friction for RM-04-BG is shown in Fig. 16-8.

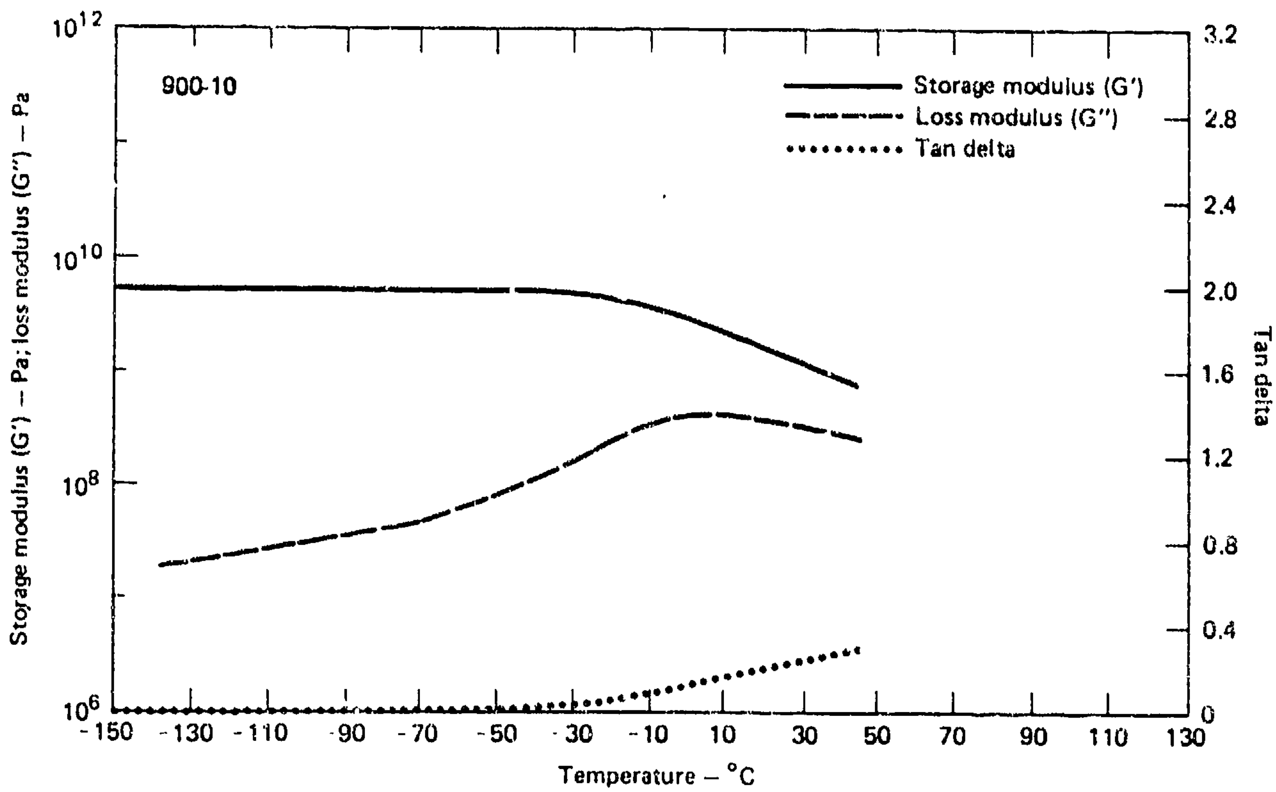


Fig. 16-7. Shear storage and loss moduli and tan δ for 900-10.[5]

Table 16-1. Static friction of mock HEs.[6]

		Contact surface and roughness						
		Dry						
		Aluminum		Plexiglas			Mild steel	
Material	Roughness	8	10	1	3	7	8	10
900-10:	Pressed	0.414	0.364	0.319	0.332	0.381	0.310	0.210
	Machined	0.374	0.332	0.306	0.290	0.384	0.287	0.210
905-03:	Pressed	0.319	0.322	0.595	0.456	0.312	0.265	0.222
	Machined	0.381	0.351	0.423	0.291	0.312	0.281	0.188
RM-04-BG:	Pressed	0.428	0.439	0.481	0.541	0.547	0.433	0.306
	Machined	0.381	0.445	0.590	0.344	0.578	0.537	0.361

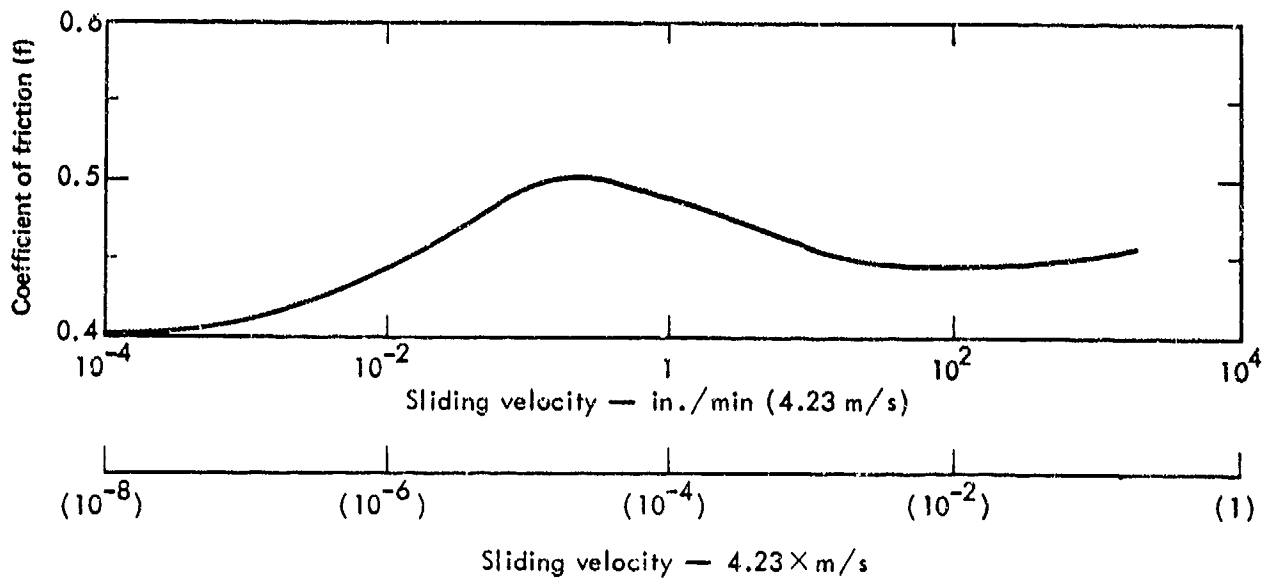


Fig. 16-8. Kinematic coefficient of friction for RM-04-BG.[7]

16.4. HUGONIOT DATA

16.4.1. Shock loading

Results from narrow-pulse flyer plate impact tests are shown in Fig. 16-9 as a plot of particle velocity vs shock velocity. Input and output pulses were generated experimentally at three depths in explosive simulants by a 0.28-mm thick, foam-backed aluminum plate. Figure 16-10 shows sustained shock-loading effects from flyer-plate impact tests. Output pulses were generated experimentally at three depths (mm) in explosive simulants by a 3.05-mm thick, foam-backed aluminum impactor.

16.4.2. Sound velocities and unreacted Hugoniots

The Hugoniots of unreacted mock HEs were determined from Marsh's measured sound velocities[8] (Table 16-2) and are summarized in Table 16-3.

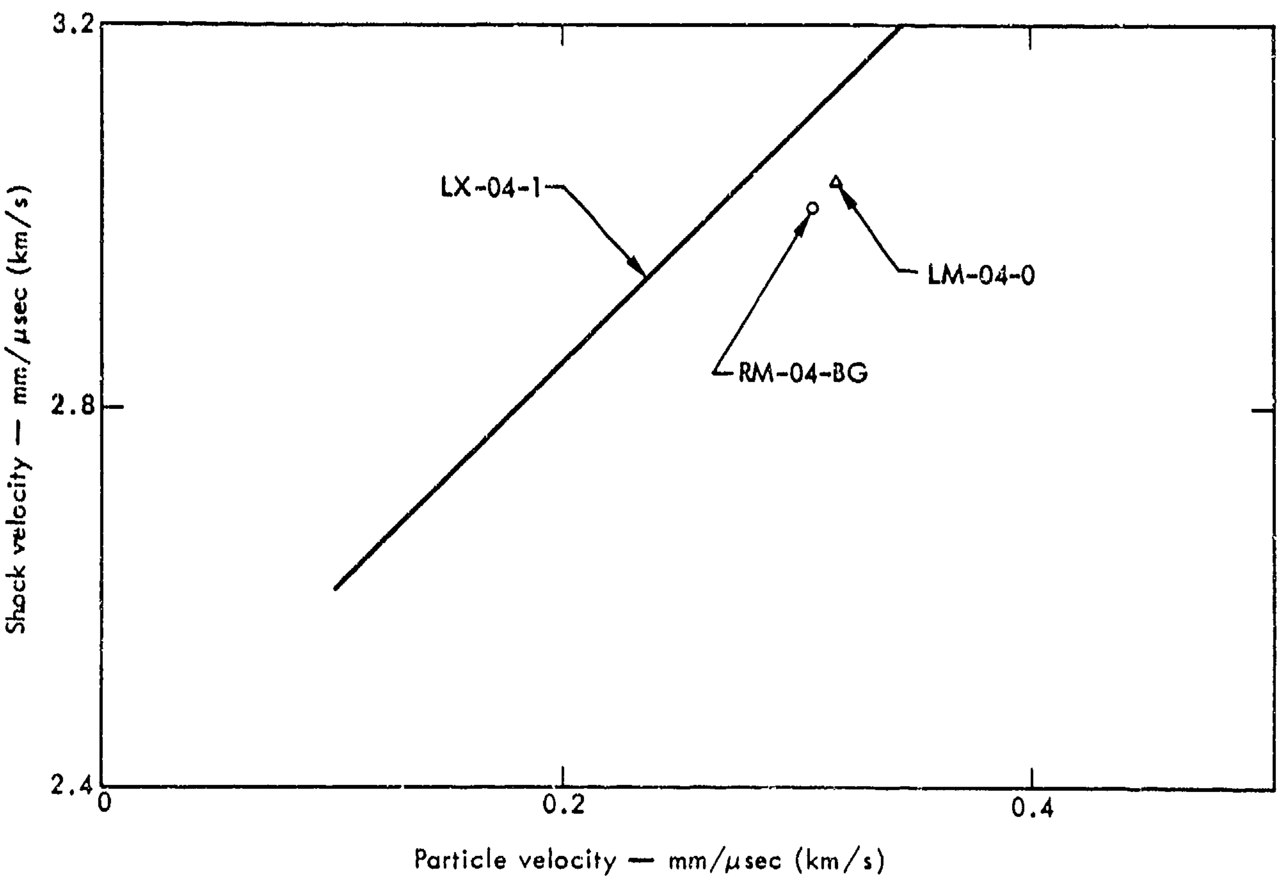


Fig. 16-9. Shock velocity vs particle velocity for mock HEs and LX-04-1.[9]

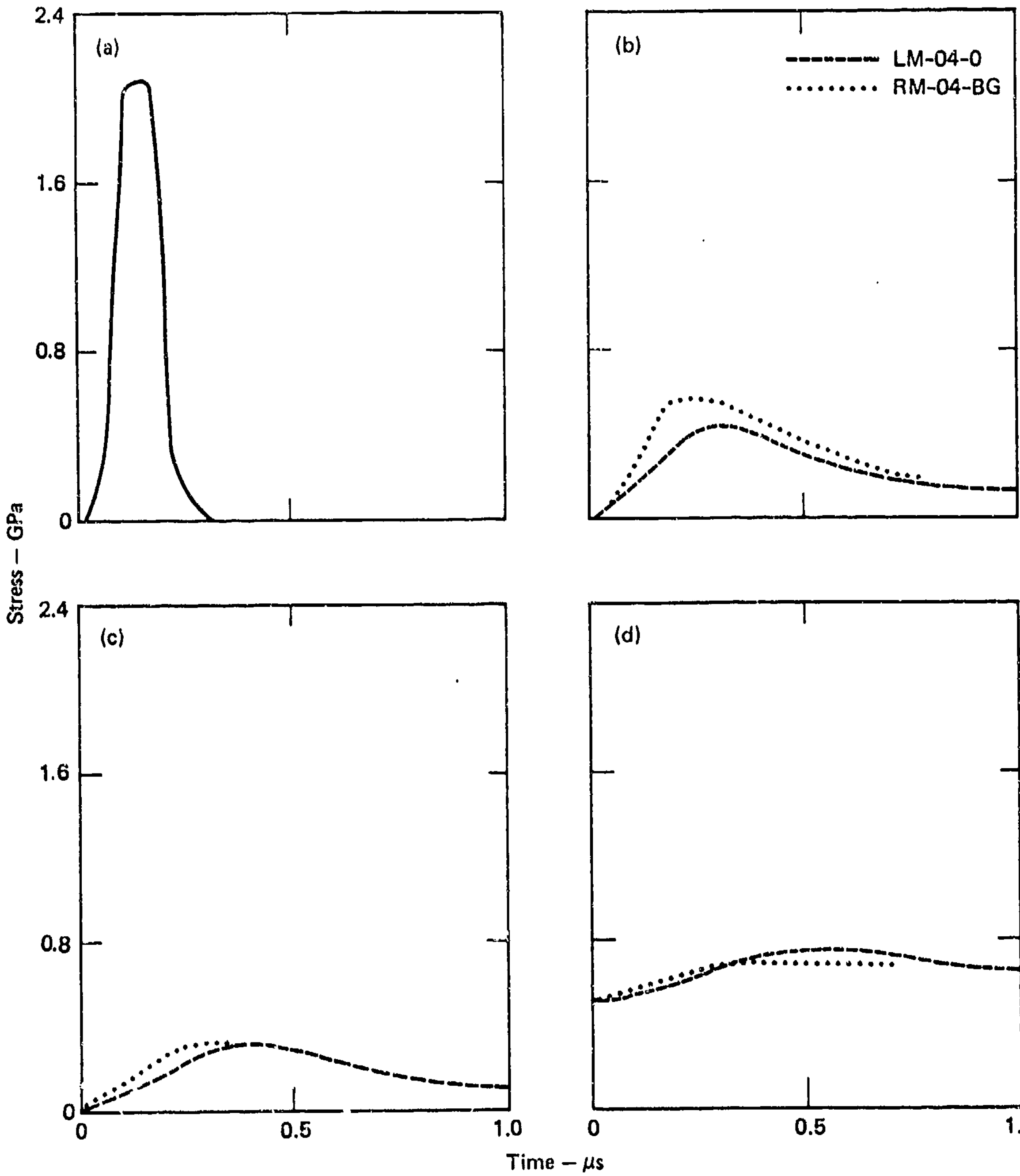


Fig. 16-10. Input and output pulses generated experimentally at three depths in LM-04-0 and RM-04-BG by a 0.28-mm-thick (nominal) aluminum driver plate backed with foam. (a) Input pulse, (b) 3.1-mm depth, (c) 6.2-mm depth, and (d) 9.5-mm depth. Conversion factor: 1 bar = 10^5 Pa.[9]

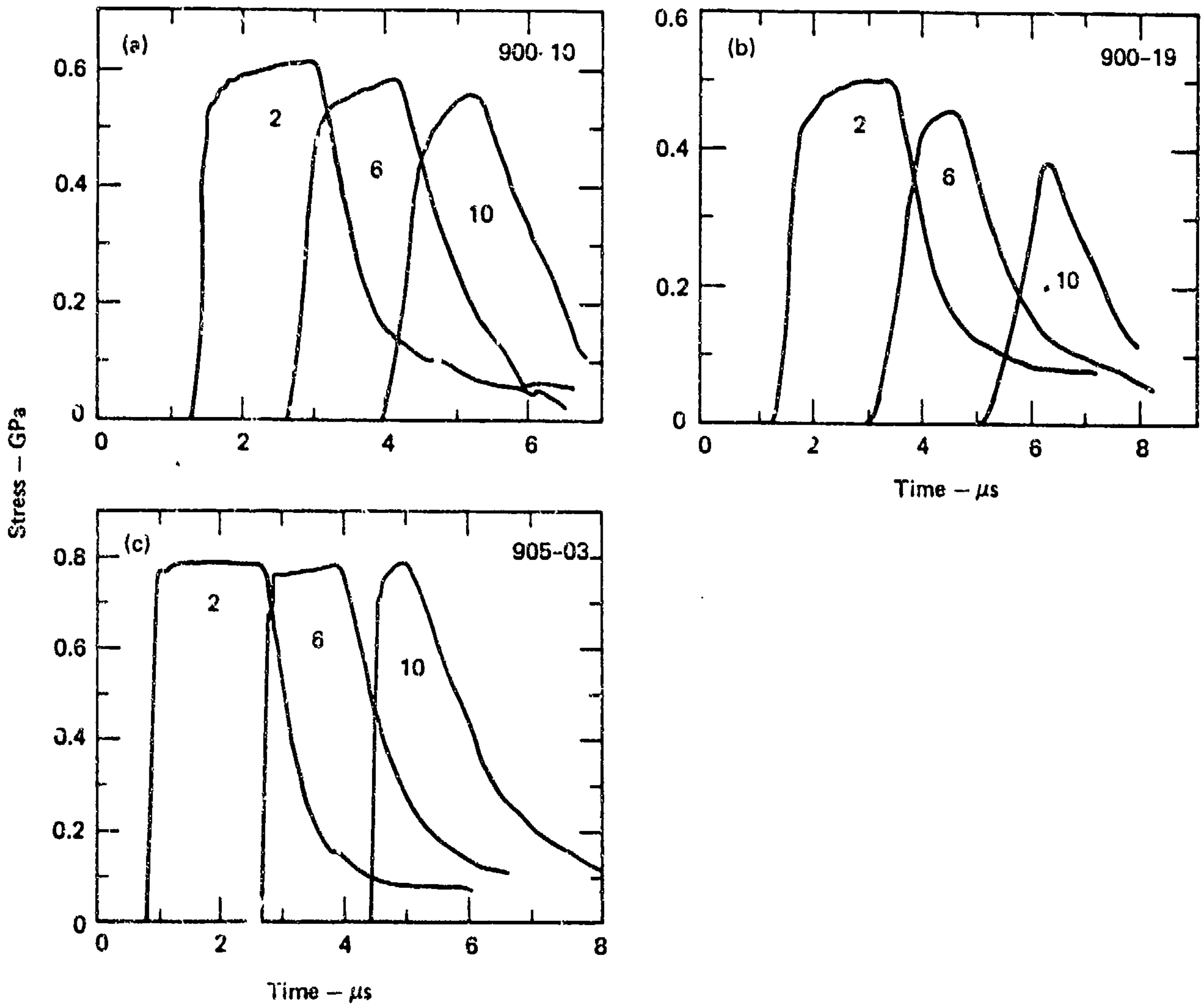


Fig. 16-11. Output pulses generated experimentally at three depths (2, 6, and 10 mm) in mock 900-10, 900-19, and 905-03 by a 3.05-mm-thick aluminum, foam-supported impactor. The impact velocities (km/s) were (a) 0.210, (b) 0.298, and (c) 0.416.[10]

Table 16-2. Sound velocities.

Mock	Density, ρ [g/cm³ (Mg/m³)]	c_ℓ (km/s)	c_s (km/s)	c_b (km/s)
900-10	1.84	3.22	1.56	2.67
	1.88	3.21	1.56	2.65
900-19	1.64	2.59	1.29	2.12
905-03	1.61	2.70	1.48	2.09
	1.60	2.22	1.16	1.96[a]

[a] This sample was found to be anisotropic, and its bulk velocity was estimated from additional measurements on another sample.

Table 16-3. Least squares fits for Hugoniots of unreacted mock HEs.

Mock	Density, ρ [g/cm³ (Mg/m³)]	Equation	Range (km/s)
900-10	1.84	$U_s = 2.70 + 1.62\ U_p$	
905-03	1.61	$U_s = 2.67 + 1.57\ U_p$	$U_s < 6.28$
	1.61	$U_s = 3.39 + 1.25\ U_p$	$U_s > 6.27$

16.5. REFERENCES

1. R. C. Murray, Lawrence Livermore National Laboratory, Livermore, CA, personal communication (1970).

2. K. G. Hoge, Applied Polymer Symposia 5, 19-40 (1967).

3. K. G. Hoge, Explosivstoffe 18, 39-41 (1970).

4. K. Scribner, A Physical Properties Mock For LX-04-1, Lawrence Livermore National Laboratory, Livermore, CA, UCID-15495 (1965).

5. D. M. Hoffman, Lawrence Livermore National Laboratory, Livermore, CA, personal communication, 1980.

6. J. R. Anthony and R. W. Ashcraft, Coefficient of Static Friction Between Explosives and Machine Surfaces, Mason & Hanger-Silas Mason Co., Inc., Pantex Plant, Amarillo, TX, MHSMP-79-11 (1979).

7. K. G. Hoge, "Friction and Viscoelastic Properties of Highly Filled Polymers: Plastic-Bonded Explosives," in Developments in Theoretical and Applied Mechanics, Vol. 4 (Pergamon Press, Oxford, 1970), pp. 371-392.

8. S. Marsh, Los Alamos National Laboratory, Los Alamos, NM, personal communication (1974).

9. R. J. Wasley and R. H. Valentine, Shock-Pulse Attenuation and Hugoniot Studies of Three Explosives and Three Mock Explosives, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-50950 (1970).

10. B. Olinger and J. W. Hopson, "Dynamic Properties of Some Explosives and Explosive Simulants," in Proc. Symp. (Int.) on High Dynamic Pressures, Paris, France (1979), pp. 9-19.

III. FORMULATION DESIGNATIONS (CODES)

This section defines and describes the codes in use at LLNL and LANL for designating explosive materials. Three categories of explosives are covered: LLNL formulations in production, LLNL research formulations, and LANL PBX designations. The code for each type is distinctive and easily recognized.

17. LLNL CODE DESIGNATIONS

17.1. FORMULATIONS IN PRODUCTION (LX CODE)

A specific code designation in this category is assigned to an explosive when the state of development of its formulation has reached the point where:

1. A set of reasonable manufacturing specifications can be written for the developed formulation.
2. The evaluation of the material's chemical, physical, explosive properties and sensitivity is essentially complete.
3. The material has a definite application.

This code consists of the two letters (LX), a dash, two digits, a second dash, and a single digit. Thus we have LX-01-0, LX-02-1, ..., LX-05-0, etc. The first pair of digits is an arbitrary serial number assigned in sequence. The final digit denotes a subclass in the series; it indicates the small changes in manufacturing specifications that inevitably occur. For example, when LX-04-0 has undergone a revision of explosive particle size, new lots manufactured under the revised specification are identified as LX-04-1.

<u>LX-01</u> A liquid material, characterized by a wide liquid range [-65° to +165°F (219-347 K)], moderate energy release, and good stability and sensitivity properties.

<u>LX-02</u> A material of puttylike texture characterized by its ability to propagate in very small diameters. LX-02 is derived from a series of DuPont formulations, the EL-506 series. Its immediate predecessor in development, called EL-506 L-3, represented one of several LLNL

modifications to DuPont's EL-506D. EL-506 L-3 became LX-02-0, and differed from the above composition by including a few tenths of a percent of a red dye (DuPont Oil Red). Later, the dye was omitted because it tended to migrate out of the explosive under certain conditions.

<u>LX-04</u> A solid explosive characterized by excellent mechanical and compatibility properties, an energy release about 9% less than LX-09, and sensitivity properties much superior to LX-09.

<u>LX-07-2</u> A modification of LX-04 with a higher energy release (5% less than LX-09) obtained at the expense of some degradation in mechanical properties (e.g., less elongation) and in sensitivity.

<u>LX-08</u> An extrudable, curable explosive developed for use in Dautriche timing tests.

<u>LX-09</u> An explosive similar to the LANL explosive PBX-9404 but with significantly improved thermal stability and slightly poorer physical properties.

<u>LX-10</u> An explosive in the same energy class as LX-09 and PBX-9404 but that uses HMX and Viton A like LX-04 and has excellent thermal characteristics. It also exhibits high creep resistance but may be somewhat more sensitive than the other HEs.

<u>LX-11</u> An explosive like LX-04 but intentionally degraded in energy by adding an additional 5% binder.

<u>LX-13</u> A variant of the LANL explosive XTX-8003.

<u>LX-14</u> An explosive similar to PBX-9404 in energy but that uses HMX and Estane (like PBX-9011) and has excellent thermal characteristics. It exhibits higher creep resistance than LX-10 and sensitivity similar to LX-04.

<u>LX-15</u> A booster explosive based on HNS and used for detonator applications.

<u>LX-16</u> A booster explosive based on PETN and used for detonator applications.

<u>LX-17</u> A solid explosive characterized by dramatic insensitivity to mechanical stimuli, outstanding mechanical and compatibility properties, and an energy release about two-thirds that of PBX-9404. It uses TATB and Kel-F 800.

17.2. RESEARCH EXPLOSIVES (RX CODE)

Research and development programs generate a great variety of explosive formulations that never enter "production." These materials are designated "Research" explosives, and are identified by a code patterned after the LX code. The code is applied to all materials formulated in large amounts or handled by large numbers of people.

The RX code consists of the letters RX, a dash, two digits, another dash, and two capital alphabetic characters. Thus we might have RX-01-AA, RX-13-XD, etc. The two digits, assigned arbitrarily in sequence, define a general class of formulation. Thus, RX-01 refers to nitromethane liquid formulations, RX-02 to PETN extrudable formulations, etc. The two final letters in the code, also assigned arbitrarily in sequence (AA, AB, etc.) refer to a specific formulation within that general class. No correlation exists between RX and LX code-number sequences.

<u>RX-01</u> Liquid materials containing nitromethane.

<u>RX-02</u> Extrudable materials containing PETN.

<u>RX-03</u> Solid, plastic-bonded materials containing DATB or TATB.

<u>RX-04</u> Solid, plastic-bonded materials composed of HMX and fluorocarbon elastomer. A specific example is RX-04-AB (HMX/Viton A 85/15); the HMX is defined as Holston's Class A. This material is for research purposes only; it is very much more sensitive than LX-04 having the identical chemical composition.

<u>RX-05</u> Solid, plastic-bonded materials based on HMX and polystyrene.

<u>RX-06</u> Extrudable materials based on HMX/4,4-dinitropentanoic acid ester formulations.

<u>RX-07</u> Series A: Cyclotols (RDX/TNT) containing various additives. Series B: LX-07-type explosives.

<u>RX-08</u> Research explosives based on formulations of HMX, energetic liquids, and polymers. These explosives are primarily for use in polymerization/pressure-casting experiments.

<u>RX-09</u> Research explosives based on formulations of HMX and energetic binders. The binders are primarily based on plasticized poly(2,2-dinitropropylacrylate). These explosives are intended to be high-energy formulations replacing PBX-9404.

RX-10 Rigid plastic-bonded explosives containing RDX and a fluorocarbon binder. They are primarily designed as insensitive replacements of PBX-9010.

RX-11 Rigid plastic-bonded explosives containing HMX and a light metal perchlorate.

RX-12 Inert metal-loaded formulations of HMX/Viton.

RX-13 Potentially explosive materials compounded to produce color changes from the heat produced upon impact.

RX-14 HMX/polyethylene formulations. These explosives possess a very high degree of insensitivity, even though they are formulated with relatively low volume percentages of binder.

RX-15 PETN-or BTF-based rigid PBXs.

RX-16 HMX/silicone formulations made in paste or putty form using a spray-on catalyst.

RX-17 HMX-based rigid explosives using various binders and energetic plasticizers.

RX-18 Paste explosives containing HMX and a perchlorate. The carrier fluid is energetic (e.g., EDNP or FEFO).

RX-19 An extrudable explosive consisting of Class-E HMX and water with a reinforcing agent (such as milled glass fibers) and a wetting agent.

RX-20 Research explosives based on HMX and an energetic binder.

RX-21 Research explosives based on HMX, a perchlorate, and energetic binders.

RX-22 Research explosives for exploring advanced energy concepts.

RX-23 Liquid explosives based on hydrazine.

RX-24 Research explosives containing HMX, PVC/PVA, and graphite.

RX-25 Research explosives based on HMX, a light metal, a perchlorate, and a binder.

RX-26 High-temperature composite explosives based on TATB.

RX-27 High-temperature explosives based on TACOT.

RX-28 Conventional high-temperature plastic-bonded explosives.

RX-29 Explosives consisting of separate components that are nondetonable until mixed.

RX-30 Research explosives based on gelled nitromethane and various perchlorates.

RX-31 Blasting agents containing aluminum, gelled nitromethane, and ammonium nitrate.

RX-32 Explosives containing RDX, perchlorates, and curable binders. Primarily for use in polymerization casting experiments.

RX-33 Low-density explosives containing appreciable bulking agents such as foam, hollow beads, etc. Density is generally less than 1.2 g/cm^3.

RX-34 Non-ideal research explosives based on ammonium nitrate.

RX-36 Explosives containing HMX, TATB, and BTF.

18. LANL CODE DESIGNATIONS

The Los Alamos National Laboratory has a number code for designating PBX materials that reach the stage of pilot or full-scale production. The code consists of four digits, a dash, and two more digits (for example, 9010-02). The first two digits give the weight percentage of the major explosive ingredient in the formulation. The next two digits represent an arbitrary serial number, assigned in sequence as materials are developed. The digits following the dash represent a second arbitrarily assigned serial number to designate different modifications of a given formulation. Thus, PBX-9010-02 is a material that contains 90 wt% of the major explosive ingredient, is the tenth 90%-material to be developed, and is the second modification of that particular composition.

The last two digits are often deleted in references to LANL materials. Thus, production PBX-9404 should, strictly speaking, be designated PBX-9404-03. The -03 designates a product manufactured in Holston equipment from HMX with a particular particle-size distribution.

LANL research explosives carry the designation X followed by a four-digit number.

IV. DATA SHEETS: COLLECTED PROPERTIES OF EXPLOSIVES, ADDITIVES, AND BINDERS

19. DATA SHEETS

This section contains the assembled data sheets of properties of individual explosives and related materials of continuing interest to this Laboratory. Some property data given in Section I have been omitted from the data sheets. For example, critical diameters are listed only in Table 8-10. For details, conversion factors, and references, please refer to Section I.

The symbols and units used in these data sheets are listed in Table 19-1.

Table 19-1. Symbols and units used in the data sheets.

Property	Symbol	Unit
Boiling point	b.p.	°C (K)
Chapman-Jouguet pressure	P_{CJ}	kbar (GPa)
Coefficient of thermal expansion:		
linear	α	μm/m-K
cubic	β	μm/m-K
Complex shear modulus	G*	Pa
Creep compliance	J	m^2/N
Crystal data	--	Å
Density	ρ	g/cm^3 (Mg/m^3)
Detonation velocity	D	mm/μsec (km/s)
Dielectric constant	ε	-
Drop weight sensitivity	H_{50}	m
Energy (cylinder test)	E_{cyl}	$(mm/\mu sec)^2$ (MJ/kg)
Gap test	Gap	mil (mm)
Glass transition temperature	T_g	°F (K)
Heat of detonation	ΔH_{det}	kcal/g (kJ/kg)
Heat of formation	ΔH_f	kcal/mol (kJ/mol)
Initial modulus	E_o	GPa
Melting point	m.p.	°C (K)

Table 19-1. Symbols and units used in the data sheets. (Continued)

Property	Symbol	Unit
Molecular refraction	R	-
Molecular weight	MW	-
Refractive index	n	-
Skid test	Skid	ft (m)
Solubility	sol.	-
Sound velocity:		
bulk	c_b	km/s
longitudinal	c_ℓ	km/s
shear	c_s	km/s
Specific heat	C_p	cal/g-°C (kJ/kg-K)
Thermal conductivity	λ	cal/sec-cm-°C (W/m-K) Btu/hr-ft-°F (W/m-K)
Vapor pressure	v.p.	mm Hg (Pa)

EXPLOSIVE: AMATOL 80/20	DESIGNATION: **Amatol 80/20**

2. STRUCTURE OR FORMULATION

	wt%
Ammonium nitrate	80
TNT	20

4. PHYSICAL PROPERTIES

Physical state: solid

Color: buff/yellow

At. comp.: $C_{0.62}\ H_{4.44}\ N_{2.26}\ O_{3.53}$

MW: 100

Density (g/cm^3): TMD: 1.710

Nominal: 1.46 cast

m.p. (°C (K)):

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.20 (5.02)	0.976 (4.08)
Exp:	1.02 (4.27)	

ΔH_f (kcal/100g (kJ/100g)): -88.6 (-370.8)

Solubility (s-sol., sl-sl. sol., i-insol.):

6. THERMAL PROPERTIES

λ:

CTE:

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr:

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 5.2 (ρ= 1.6)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.:

Calc.:

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ=)

6 mm:

19 mm:

9. SENSITIVITY

H_{50} (m): 12 tool 12B tool

Susan test:

Skid test:

Impact angle (deg (rad)) Drop ht. (ft (m)) Event

Gap test (mils (mm)): (ρ=)

10. ELECTRICAL PROPERTIES:

ε:

11. TOXICITY

Moderate

Amatol 80/20

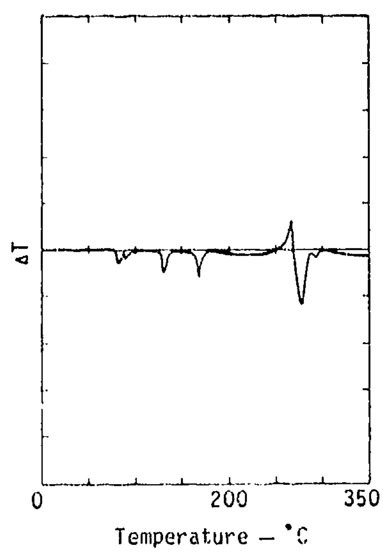
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

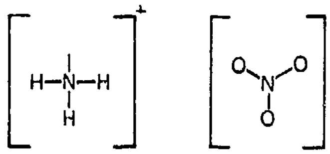


DTA curve

EXPLOSIVE: AMMONIUM NITRATE

DESIGNATION: **AN**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: clear

At. comp.: NH_4NO_3

MW: 80.05

Density (g/cm^3): TMD: 1.725

Nominal: 1.72

m.p. (°C (K)): 169 (442)
b.p. (°C (K)): dec. 210 (483) dec.
v.p. (mm Hg (Pa)):

Crystal data:

	AN III Orthorhomic (Pnma)	AN II Tetragonal (P4/mbm)	AN I Cubic (Pm3m)
a	= 7.72	5.7	4.37
b	= 5.85		
c	= 7.16	4.93	

R:

n: 1.53

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:		
Exp:		

ΔH_f (kcal/mol (kJ/mol)): −87.27 (−365.1)

Solubility (s--sol., sl--sl. sol., i--insol.):

s--water, DMFA, nitric acid
sl--ethanol, pyridine
i--acetone, ethyl acetate, ethyl ether

6. THERMAL PROPERTIES

λ: 2.9–3.9 × 10^{-4} cal/cm-sec-°C (0.121–0.163 W/m-K)

CTE: β = 982 μm/m-K at 293 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):
Est. 0.4 at 0°C (1.67 at 273 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr:

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): ~1.5 (ρ= ~0.7)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.:

Calc.:

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ =)

6 mm:

19 mm:

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	--	--
2.5 kg:	1.36	>3.20

Susan test:

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event

Gap test (mils (mm)): (ρ=)

10. ELECTRICAL PROPERTIES:

ε: ~7.1 (ρ = 1.67)

11. TOXICITY

Low

1/82

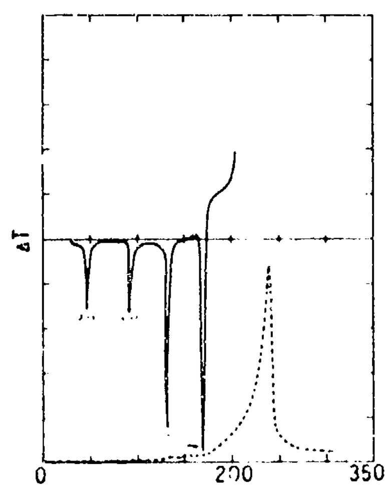
7. MECHANICAL PROPERTIES

Initial modulus

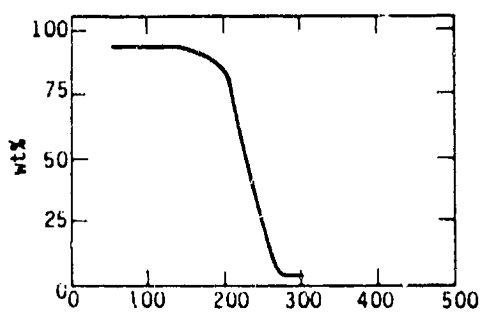
Creep

Failure envelope

NOTES



DTA (—) and pyrolysis (--) curves

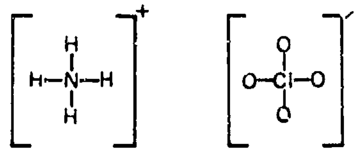


TGA curve

EXPLOSIVE: AMMONIUM PERCHLORATE

DESIGNATION: **AP**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: NH_4ClO_4

MW: 117.5

Density (g/cm^3): TMD: 1.95

Nominal:

m.p. (°C (K)): >220 with dec. (493 dec.)

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

Crystal data:

	Orthorhombic <240°C (Pnma)	Cubic >240°C (F43m)
a	9.23	7.67
b	7.45	
c	5.82	

R:

n: 1.48

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:		
Exp:		

ΔH_f (kcal/mol (kJ/mol)): -70.58 (-295)

Solubility (s-sol., sl-sl. sol., i-insol.):
s--DMFA, water
sl--acetone, ethanol
i--ethyl ether, ethyl acetate

6. THERMAL PROPERTIES

λ: 12.0×10^{-4} cal/cm-sec-°C (0.502 W/m-K) at 323 K

CTE: α = ~40 μm/m-K at 293 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):
Est. 0.31 at 15-240°C (1.29 at 288-513 K)
Est. 0.37 at >240°C (1.53 at >513 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr:

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): (ρ=)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.95)

Meas.:

Calc.: 187

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ=)

6 mm:

19 mm:

9. SENSITIVITY

H_{50} (m): 12 tool 12B tool

Susan test:

Skid test:
Impact angle (deg (rad)) Drop ht. (ft (m)) Event

Gap test (mils (mm)): (ρ=)

10. ELECTRICAL PROPERTIES:

ε:

11. TOXICITY

Low

7. MECHANICAL PROPERTIES

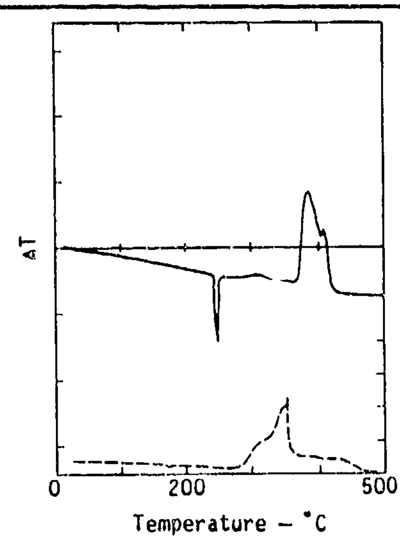
Sound velocity (km/s):	c_ℓ	c_s	c_b
(ρ = 1.95)	--	--	2.84

Initial modulus

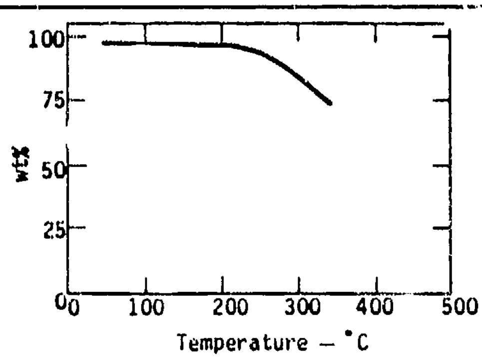
Creep

Failure envelope

NOTES



DTA (—) and pyrolysis (--) curves



TGA curve

EXPLOSIVE: BARATOL

DESIGNATION: **Baratol**

2. STRUCTURE OR FORMULATION

	wt%
TNT	24
$Ba(NO_3)_2$	76

4. PHYSICAL PROPERTIES

Physical state: solid

Color:

At. comp.: $C_{0.74}H_{0.53}N_{0.90}O_{2.38}Ba_{0.29}$

MW: 100

Density (g/cm^3): TMD: 2.63

Nominal: 2.60-2.61

m.p. (°C (K)): 79-80 (352-353)

b.p. (°C (K)):

v.p. (mm Hg (Pa)): 0.1 at 100°C (13.33 at 373 K)

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	0.74 (3.10)	0.72 (3.01)
Exp:		

ΔH_f (kcal/100g (kJ/100g)): -70.6 (-296)

Solubility (s-sol., sl-sl. sol., i-insol.):

6. THERMAL PROPERTIES

λ: 11.84×10^{-4} cal/cm-sec-°C (0.495 W/m-K) at 291-348 K

CTE:

α = 33 + 0.26T μm/m-K at 233-333 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Exp. 0.157 at 30°C (0.657 at 303 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.015-0.02

1 g for 48 hr: 0.19

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 4.87 (ρ = 2.55)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 2.61)

Meas.: --

Calc.: 140

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ =)

6 mm:

19 mm:

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.95	--
2.5 kg:	0.68--1.4	0.98--1.8

Susan test:

Skid test:

Impact angle (deg (rad)) Drop ht. (ft (m)) Event

Gap test (mils (mm)): (ρ =)

NSWC-SSGT:		
LANL-SSGT:	NO GO	(ρ = 2.565)
LANL-LSGT:	(27.30)	(ρ = 2.597)
PX-GT:	(8.76)	(ρ = 2.610)
SRI-GT:		

10. ELECTRICAL PROPERTIES:

ε: 4.12 (ρ = 2.59)

11. TOXICITY

Baratol

7. MECHANICAL PROPERTIES

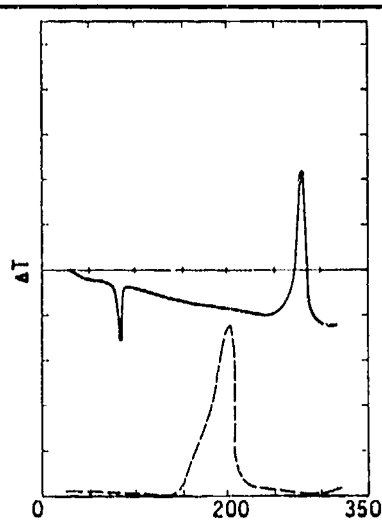
Sound velocity (km/s):	c_ℓ	c_s	c_b
(ρ = 2.611)	2.95	1.48	2.40

Initial modulus

Creep

Failure envelope

NOTES



DTA (—) and pyrolysis (--) curves

MATERIAL: BIS(2,2-DINITROPROPYL)ACETAL/ BIS(2,2-DINITROPROPYL)FORMAL (Plasticizer) 50/50 wt%	DESIGNATION: **BDNPA-F** SUPPLIER: —

2. STRUCTURAL FORMULATION

	wt%	
BDNPA	50	$CH_3C(NO_2)_2CH_2\text{-}O\text{-}CH(CH_3)\text{-}O\text{-}CH_2C(NO_2)_2CH_3$
BDNPF	50	$CH_3C(NO_2)_2CH_2\text{-}O\text{-}CH_2\text{-}O\text{-}CH_2C(NO_2)_2CH_3$

4. PHYSICAL PROPERTIES

Physical state: liquid
Color: straw
At. comp.:
MW:
Density (g/cm^3): TMD:
Nominal: 1.383-1.397 at 25°C (298 K)
m.p. (°C (K)):
b.p. (°C (K)): ~150 at 0.01 mm Hg (~423 at 1.33 Pa)
v.p. (mm Hg (Pa)):
Brittle point (°C (K)):
f.p. (°C (K)): <-5 (<268)

Crystal data:

R:
n: 1.462-1.464 at 25°C (298 K)
Shore hardness:

5. CHEMICAL PROPERTIES

ΔH_f (kcal/mol (kJ/mol)):
-46.38 kcal/100 g (-194.1 kJ/0.1 kg)
Solubility (s-sol., sl-sl. sol., i-insol.):
s – benzene, toluene
i – water

7. MECHANICAL PROPERTIES

Tensile strength (psi (kPa)):

Elongation (%):

6. THERMAL PROPERTIES

λ:
CTE:

T_g (°F (K)):
C_p (cal/g-°C (kJ/kg-K)):

10. ELECTRICAL PROPERTIES

ϵ: (ρ =

11. TOXICITY

None.

NOTES

EXPLOSIVE: BLACK POWDER

2. STRUCTURE OR FORMULATION

	wt%
KNO_3 or $NaNO_3$	75
Charcoal	15
S	10

4. PHYSICAL PROPERTIES

Physical state: granular

Color: gray to black

At. comp.: $C_{\sim 10-12}$ $H_{\sim 0.5}$ $N_{\sim 11}$ $O_{\sim 36}$ $K_{\sim 29}$ $S_{\sim 10}$ $Ash_{\sim 0.5}$

MW:

Density (g/cm^3): TMD: ≤2.0

Nominal: ~1.91-1.95

m.p. (°C (K)):
b.p. (°C (K)):
v.p. (mm Hg (Pa)):

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:		
Exp:		

ΔH_f (kcal/mol (kJ/mol)):

Solubility (s - sol., sl - sl. sol., i - insol.):

6. THERMAL PROPERTIES

λ:

CTE:

DESIGNATION: **Black Powder**

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr:

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): ~1.35 (ρ= ~0.9-1.1)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.:

Calc.:

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm:

19 mm:

9. SENSITIVITY

H_{50} (m): 12 tool 128 tool

Susan test:

Skid test:

Impact angle (deg (rad)) Drop ht. (ft (m)) Event

Gap test (mils (mm)): (ρ=)

10. ELECTRICAL PROPERTIES:

ε:

11. TOXICITY

Black Powder

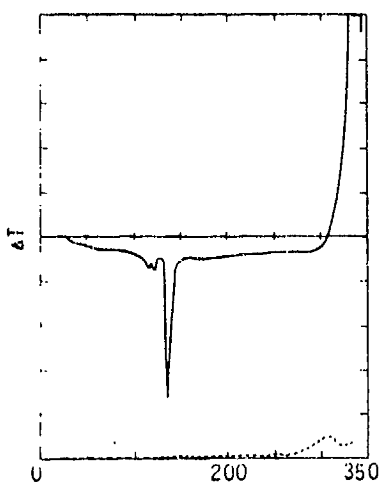
7. MECHANICAL PROPERTIES

Initial modulus

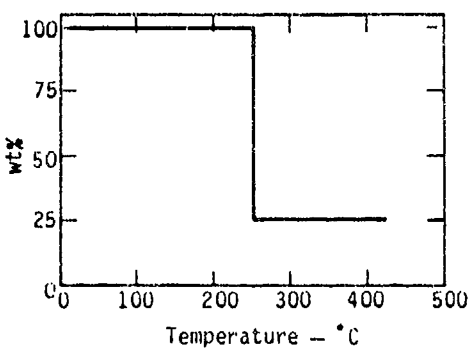
Creep

Failure envelope

NOTES



DTA curve



TGA curve

EXPLOSIVE: BORACITOL	DESIGNATION: **Boracitol**

2. STRUCTURE OR FORMULATION

	wt%
TNT	40
Boric acid	60

4. PHYSICAL PROPERTIES

Physical state: solid

Color:

At. comp.: $C_{1.23}H_{3.79}N_{0.53}O_{3.97}B_{0.97}$

MW: 100

Density (g/cm^3): TMD:

Nominal: 1.53-1.54

m.p. (°C (K)): 79-80 (352-353)

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	0.40 (1.67)	0.20 (0.84)
Exp:		

ΔH_f (kcal/100g (kJ/100g)): -256.6 (-1074)

Solubility (s-sol., sl-sl. sol., i-insol.):

6. THERMAL PROPERTIES

k:

CTE: α = 46.7 μm/m-K at 273-333 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr:

1 g for 48 hr: 0.02-0.04

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 4.86 (ρ= 1.55)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.:

Calc.:

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm:

19 mm:

9. SENSITIVITY

H_{50} (cm (10^{-2} mm)):	12 tool	12B tool
5 kg:	>1.77	
2.5 kg:	>3.20	>3.20

Susan test:

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event

Gap test (mils (mm)): (ρ=)

10. ELECTRICAL PROPERTIES:

ϵ: 2.84 (ρ = 1.53)

11. TOXICITY

Boracitol

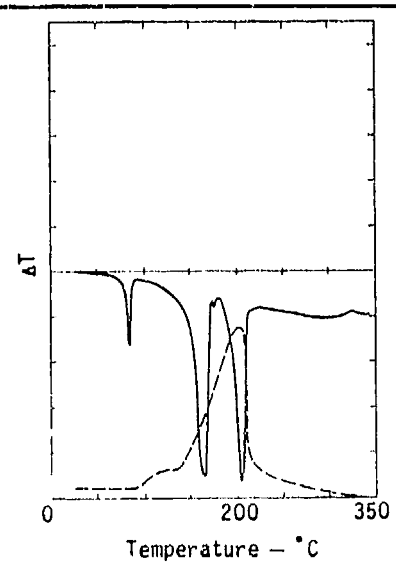
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

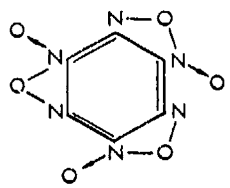


DTA (—) and pyrolysis (--) curves

EXPLOSIVE: BENZOTRIS [1,2,5] OXADIAZOLE, 1,4,7-TRIOXIDE

DESIGNATION: **BTF**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: buff

At. comp.: $C_6N_6O_6$

MW: 252.1

Density (g/cm^3): TMD: 1.901

Nominal: 1.87

m.p. (°C (K)): 198-200 (471-473)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: orthorhombic ($Pna2_1$)

a = 6.92
b = 19.52
c = 6.52

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.69 (7.07)	1.69 (7.07)
Exp:	1.41 (5.90)	1.41 (5.90)

ΔH_f (kcal/mol (kJ/mol)): +144.5 (+606)

Solubility (s-sol., sl-sl. sol., i-insol.):
s — acetone, benzene, DMFA, DMSO, ethanol, ethyl acetate, ethyl ether, pyridine
i — carbon tetrachloride, water

6. THERMAL PROPERTIES

λ: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est. 0.3 (1.25)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.24-0.40
0.05 (purified)

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.49 (ρ = 1.86)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.859)

Meas.: 360

Calc.: 309

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ = 1.859)

6 mm: 1.305

19 mm: 1.680

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.11	--
2.5 kg:	~0.21	--

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (ρ=)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

—

BTF

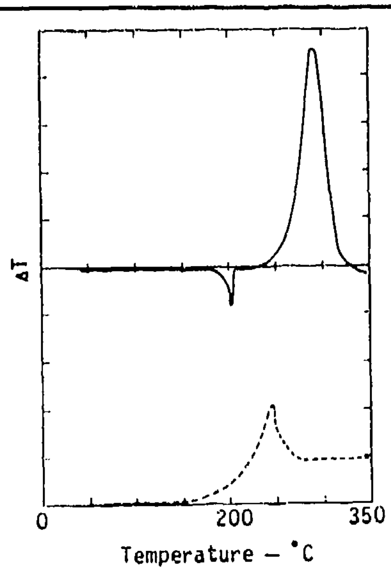
7. MECHANICAL PROPERTIES

Initial modulus

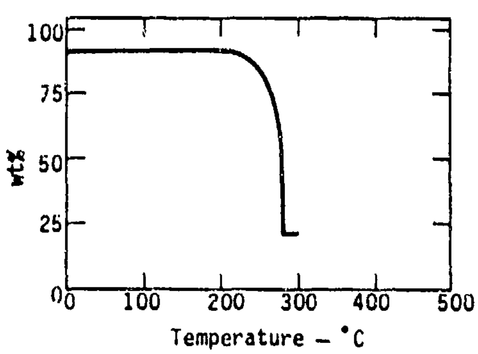
Creep

Failure envelope

NOTES



DTA (—) and pyrolysis (--) curves



TGA curve

MATERIAL: AMORPHOUS SILICON OXIDE (Gelling agent)	DESIGNATION : **Cab-O-Sil** SUPPLIER : Cabot Corp.

2. STRUCTURAL FORMULATION

$[O - Si - O]_n$

4. PHYSICAL PROPERTIES

Physical state : solid (fluffy powder)	Crystal data : amorphous
Color : white	
At. comp. : SiO_2	
MW : $[60.09]_n$	
Density (g/cm^3) : TMD : 2.3	
Nominal : 2.2	
m.p. (°C (K)) :	R :
b.p. (°C (K)) :	n : 1.46
v.p. (mm Hg (Pa)) :	Shore hardness :
Brittle point (°C (K)) :	
f.p. (°C (K)) :	

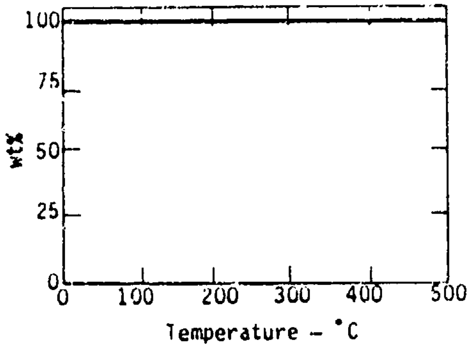
5. CHEMICAL PROPERTIES	7. MECHANICAL PROPERTIES
ΔH_f (kcal/mol (kJ/mol)) : -215.94 (-903.5)	Tensile strength (psi (kPa)):
Solubility (s-sol., sl-sl. sol., i- insol.) : nil	Elongation (%) :

6. THERMAL PROPERTIES	10. ELECTRICAL PROPERTIES
λ :	ϵ : (ρ =
CTE :	
	11. TOXICITY
T_g (°F (K)) :	Low.
C_p (cal/g-°C (kJ/kg-K)) :	

NOTES

3/81

Cab-O-Sil



TGA curve

MATERIAL: TRIS-β-CHLOROETHYL PHOSPHATE (Plasticizer)	DESIGNATION : **CEF** SUPPLIER :

2. STRUCTURAL FORMULATION

$$O = P - (O - CH_2 - CH_2Cl)_3$$

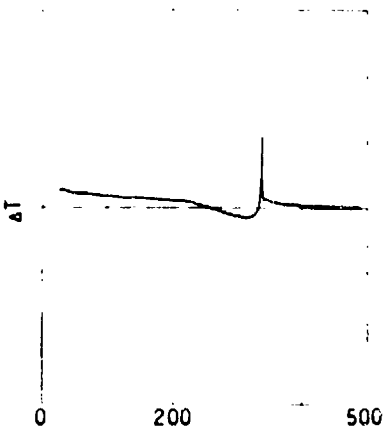
4. PHYSICAL PROPERTIES

Physical state : liquid Color : clear At. comp. : $C_6H_{12}Cl_3O_4P$ MW : 285.5 Density (g/cm^3) : TMD : 1.425 Nominal : m.p. (°C (K)) : 203 (476) b.p. (°C (K)) : v.p. (mm Hg (Pa)) : Brittle point (°C (K)) : -60 (213 K) f.p. (°C (K)) :	Crystal data : R : n : Shore hardness :

5. CHEMICAL PROPERTIES	7. MECHANICAL PROPERTIES
ΔH_f (kcal/mol (kJ/mol)) : -300 (-1255) Solubility (s-sol., sl-sl sol., i-insol.) : s – alcohols, benzene, carbon tetrachloride, chloroform, esters, ethers, ketones, toluene, xylene i – aliphatic hydrocarbons, water	Tensile strength (psi (kPa)): Elongation (%) :

6. THERMAL PROPERTIES	10. ELECTRICAL PROPERTIES
λ : CTE : β = 840 μm/m-K T_g (°F (K)) : C_p (cal/g-°C (kJ/kg-K)) :	ε : (ρ = **11. TOXICITY** Moderate when ingested

NOTES



DTA curve

EXPLOSIVE: COMP A-3, COMP A-5

DESIGNATION: **Comp A**

2. STRUCTURE OR FORMULATION

	wt% A-3	wt% A-5
RDX	91	98.5-99.0
WAX	9	
Stearic acid		1.5- 1.0

4. PHYSICAL PROPERTIES

	A-3	A-5
Physical state:	granular	granular
Color:	white/buff	white/buff
At. comp.:	$C_{1.87}H_{3.74}N_{2.46}O_{2.46}$	$C_{1.41-1.44}H_{2.82-2.88}N_{2.66-2.67}O_{2.66-2.67}$
MW:		
Density (g/cm^3): TMD:	1.672	1.757
Nominal:	1.65 pressed	1.70 pressed

m.p. (°C (K)): A-3:200 (473)

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):

		H_2O (ℓ)	H_2O (g)
A-3	Calc:	1.58 (6.61)	1.39 (5.82)
A-5	Calc:	1.62 (6.78)	1.61-1.62(6.74-6.78)

ΔH_f (kcal/mol (kJ/mol)): A-3: +2.84 (+11.9)
A-5: +~6.1 (+~25.5)

Solubility (s-sol., sl-sl. sol., i-insol.):

6. THERMAL PROPERTIES

λ:

CTE:

Comp A-3: α = 71.7 μm/m-K at 253-293 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr:

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): A-3: 8.47 (ρ= 1.64)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.:

Calc.:

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.59)

6 mm:

19 mm: A-3: ~1.20

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	--	--
A-3: 2.5 kg:	0.81	2.45
A-4: 2.5 kg:	0.37	1.12

Susan test: A-3: Difficult to ignite by mechanical means; low probability for buildup to violent reaction at light confinement.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event

Gap test (mils (mm)): (ρ=)

NSWC-SSGT:	A-5:	(8.79)	(ρ = 1.700)
LANL-SSGT:	A-3:	(0.89)	(ρ = 1.635)
LANL-LSGT:	A-3	(54.51)	(ρ = 1.638)
PX-GT:			
SRI-GT:			

10. ELECTRICAL PROPERTIES:

ε:

11. TOXICITY

Comp A

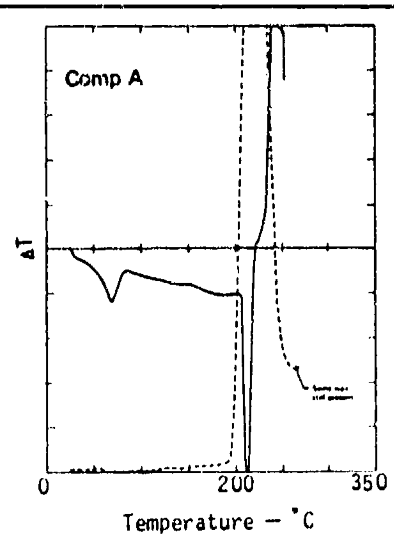
7. MECHANICAL PROPERTIES

Initial modulus

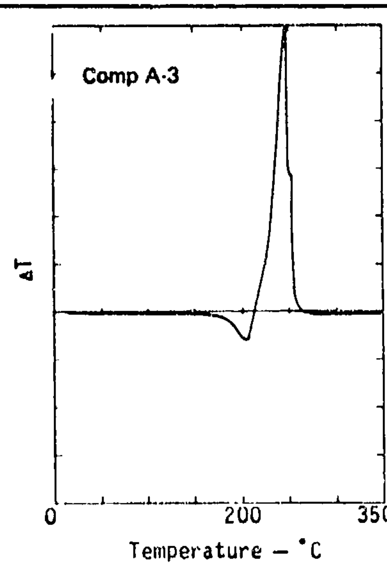
Creep

Failure envelope

NOTES



DTA (—) and pyrolysis (--) curves



DTA curve

EXPLOSIVE: COMP B, GRADE A, COMP B-3

DESIGNATION: **Comp B**

2. STRUCTURE OR FORMULATION

	Comp B wt%	Comp B-3 wt%
RDX	63	60
TNT	36	40
WAX	1	

4. PHYSICAL PROPERTIES

Physical state: solid

Color: yellow/buff

At. comp.: $C_{2.03}H_{2.64}N_{2.18}O_{2.67}$ $C_{2.05}H_{2.51}N_{2.15}O_{2.67}$

MW: 100

Density (g/cm^3): TMD: 1.742 1.75

Nominal: 1.71 1.72

m.p. (°C (K)): ~80 (~353) 79-80

b.p. (°C (K)): --

v.p. (mm Hg (Pa)): -- B-3: 0.1 (13.33) at 100°C

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.54 (6.44)	1.40 (5.86)
Exp:	1.20 (5.02)	--
B-3 calc:	1.54 (6.44)	1.40 (5.86)
Exp:	1.20 (5.02)	1.12 (4.69)

ΔH_f (kcal/100g (kJ/100g)): B: + 1.28 (+ 5.38)

B-3: + 1.15 (+ 4.81)

Solubility (s-sol., sl-sl. sol., i-insol.):

6. THERMAL PROPERTIES

λ: B: 5.4×10^{-4} cal/cm-sec-°C (0.226 W/m-K) at 298 K

B-3: 6.27×10^{-4} cal/cm-sec-°C (0.262 W/m-K) at 291-348K

CTE:

Comp B: α = 54.6 μm/m-K at 279-298 K

α = 97.5 μm/m-K at 300-336 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Comp B: Exp. 0.27 at 25°C (1.13 at 298 K)

B-3: Exp. 0.299 at 30°C (1.25 at 303 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr:	0.051	Comp B
	0.033	Comp B-3
1 g for 48 hr:	0.05-0.16	Comp B
	0.27	Comp B-3

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): Comp B: 7.92 (ρ = 1.72)

Comp B-3: 7.89 (ρ = 1.72)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.717)

Meas.: 295

Calc.: --

B-3: Meas.: 287 (ρ = 1.715)

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ =)

	Comp B (ρ = 1.717)	Comp B-3 (ρ = 1.728)
6 mm:	1.035	1.01
19 mm:	1.330	1.322

9. SENSITIVITY

H_{50} (m):		12 tool	12B tool
Comp B:	5 kg	0.45	--
	2.5 kg	0.49-0.85	0.98-3.0
B-3:	5 kg	0.29	0.65
	2.5 kg	0.4-0.8	0.69-1.2

Susan test: B-3: Threshold velocity is ~180 ft/sec (55 m/s); generally difficult to ignite, low probability for violent reaction at light confinement.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
B-3: 14 (0.24)	1.25 (8.38)	2
45 (0.79)	14.1 (4.30)	2

Gap test (mils (mm)): (ρ =)

Comp B:	NSWC-SSGT:		(4.75)	(ρ = 1.735)
	LANL-SSGT:	16-26	(0.41-0.66)	(ρ = 1.710)
	LANL-LSGT:		(44.58)	(ρ = 1.712)
B-3:	LANL-SSGT:	44-54	(1.1-1.4)	(ρ = 1.721)
	LANL-LSGT:	1.982	(50.34)	(ρ = 1.727)
Comp B:	PX-GT:		(23.2)	(ρ = 1.714)

10. ELECTRICAL PROPERTIES:

ε: Comp B: 3.25 (ρ = 1.72)

B-3: 3.41 (ρ = 1.73)

11. TOXICITY

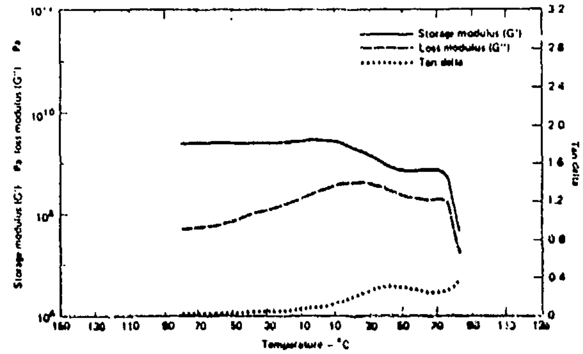
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Comp B

7. MECHANICAL PROPERTIES

B-3: Sound velocity (km/s):	C_ℓ	C_s	C_b
(ρ = 1.726)	3.12	1.71	2.42

Initial modulus

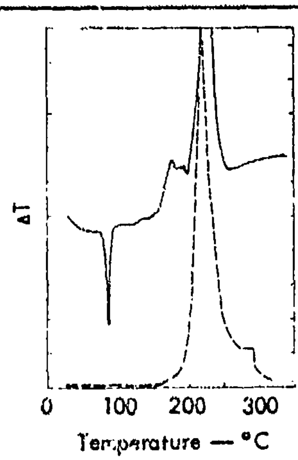


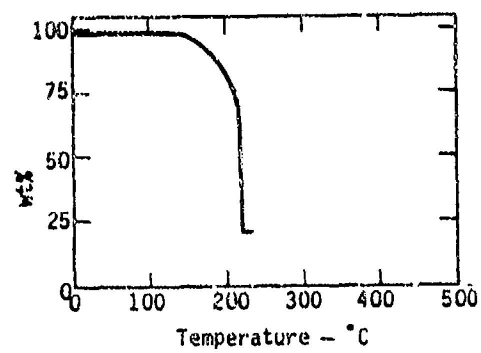
Complex shear moduli

Creep

Failure envelope

NOTES





TGA curve

DTA (-) and pyrolysis (---) curves

EXPLOSIVE: COMP C-3, COMP C-4

DESIGNATION: **Comp C**

2. STRUCTURE OR FORMULATION

	Wt% C-3		Wt% C-4
RDX	77		91
TNT	4	Di(2-ethylhexyl) sebacate	5.3
DNT	10		
MNT	5	Polyisobutylene	2.1
NC	1	Motor oil	1.6
Tetryl	3		

4. PHYSICAL PROPERTIES

Physical state: putty-like solid

Color: yellow/lt. brown (C-3); white (C-4)

At. comp.: $C_{1.90}H_{2.83}N_{2.34}O_{2.60}$ $C_{1.82}H_{3.54}N_{2.46}O_{2.51}$

MW: 100

Density (g/cm^3): TMD: -- 1.67

Nominal: 1.58-1.62 1.64-1.66

m.p. (°C (K)):
b.p. (°C (K)):
v.p. (mm Hg (Pa)):

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
C-3 Calc:	1.45 (6.07)	1.44 (6.02)
C-4	1.59 (6.65)	1.40 (5.86)
Exp:		

ΔH_f (kcal/100g (kJ/100g)): C-3: +3.74 (+15.6)
C-4: +3.33 (+13.9)

Solubility (s-sol., sl-sl. sol., i-insol.):

6. THERMAL PROPERTIES

λ: C-4: 6.22×10^{-4} cal/cm-sec-°C (0.260 W/m-K)

CTE:

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: C-4: 0.026

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): C-4: 8.37 (ρ = 1.66)
C-3: 7.63 (ρ = 1.60)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.59)

Meas.:

Calc.: C-4:257

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ = 1.601)

	C-4
6 mm:	0.962
19 mm:	1.258

9. SENSITIVITY

H_{50} (m): 12 tool 12B tool

Susan test:

Skid test:
Impact angle (deg (rad)) Drop ht. (ft (m)) Event

Gap test (mils (mm)): (ρ=)
NSWC-SSGT: C-3: (4.50) (ρ = 1.612)
C-4: (3.53) (ρ = 1.643)

10. ELECTRICAL PROPERTIES:

ε:

11. TOXICITY

C-4: Moderate

Comp C

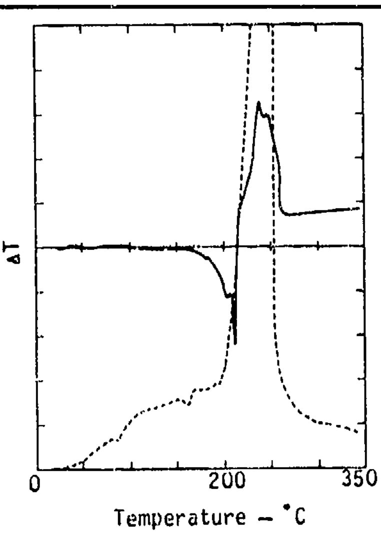
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES



DTA (—) and pyrolysis (--) curves

EXPLOSIVE: CYCLOTOL 75/25,

DESIGNATION: **Cyclotol**

2. STRUCTURE OR FORMULATION

	wt%
RDX	75
TNT	25

4. PHYSICAL PROPERTIES

Physical state: solid

Color: yellow/buff

At. comp.: $C_{1.78}H_{2.58}N_{2.36}O_{2.69}$

MW: 100

Density (g/cm^3): TMD: 1.77

Nominal: 1.75-1.76

m.p. (°C (K)): 79-80 (352-353)

b.p. (°C (K)): --

v.p. (mm Hg (Pa)): 0.1 at 100 C (13.33 at 373 K)

Crystal data: --

R: --

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.57 (6.57)	1.44 (6.02)
Exp:	--	--

ΔH_f (kcal/100g (kJ/100g)): +3.21 (+13.4)

Solubility (s-sol., sl-sl. sol., i-insol.): --

6. THERMAL PROPERTIES

λ: 75/25: 5.41×10^{-4} cal/cm-sec-°C (0.227 W/m-K)

CTE: --

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Exp. 0.254 at 25°C (1.063 at 298 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: 0.014-0.04

1 g for 48 hr: 0.25-0.94

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.30 (ρ= 1.76)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.752)

Meas.: 316

Calc.: --

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ= 1.754)

6 mm: 1.140

19 mm: 1.445

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.33	--
2.5 kg:	0.47	1.14

Susan test: Threshold velocity ~ 180 ft/sec (~55 m/s); generally difficult to ignite but capable of large reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	0.625 (0.19)	1
45 (0.79)	14.1 (4.30)	0

Gap test (mils (mm)): (ρ=)

LANL-SSGT: 10-16 (0.25-0.41) (ρ = 1.753)

LANL-LSGT: (43.15) (ρ = 1.757)

10. ELECTRICAL PROPERTIES:

ϵ: 3.38 (ρ = 1.75)

11. TOXICITY

--

Cyclotol

7. MECHANICAL PROPERTIES

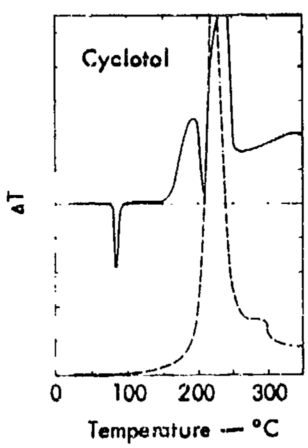
Sound velocity (km/s)	C_ℓ	C_s	C_b
(ρ = 1.752)	3.12	1.69	2.43

Initial modulus

Creep

Failure envelope

NOTES

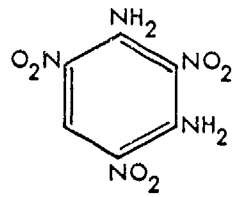


DTA (—) and pyrolysis (--) curves

EXPLOSIVE: 2,4,6-TRINITRO-1,3-BENZENEDIAMINE

DESIGNATION: **DATB**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: yellow

At. comp.: $C_6H_5N_5O_6$

MW: 243.1

Density (g/cm^3): TMD: 1.837

Nominal: 1.79

m.p. (°C (K)): 286 (559)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: (Pc)

a = 7.30
b = 5.20
c = 11.63
β = 95.9

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.26 (5.27)	1.15 (4.81)
Exp:	0.98 (4.10)	0.91 (3.81)

ΔH_f (kcal/mol (kJ/mol)): -23.6 (-98.7)

Solubility (s-sol., sl-sl. sol., i-insol.):

sl - acetone, DMFA, DMSO, butyrolactone, N-methyl-pyrrolidone

i - benzene, carbon disulfide, carbon tetrachloride, ethanol, water

6. THERMAL PROPERTIES

λ: 6.00×10^{-4} cal/sec-m-°C (0.251 W/m-K)

CTE: α = 32-45 μm/m-K at 253 K
α = 52-66 μm/m-K at 358 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Exp. 0.23 (0.962)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: < 0.03

1 g for 48 hr: < 0.03

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.52 (ρ = 1.79)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.78)

Meas.: 259

Calc.: 250

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ =)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	>1.77	>1.77
2.5 kg:	>3.20	>3.20

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):

NSWC-SSGT:		(3.28)	(ρ = 1.775)
LANL-SSGT:		(0.36)	(ρ = 1.801)
LANL-LSGT:	1.641	(41.68)	(ρ = 1.786)
PX-GT:		(17.86)	(ρ = 1.781)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

Low

3/81

DATB

7. MECHANICAL PROPERTIES

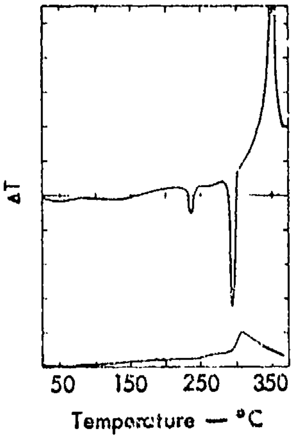
Sound velocity (km/s):	C_ℓ	C_s	C_b
(ρ = 1.78)	2.99	1.55	2.40

Initial modulus

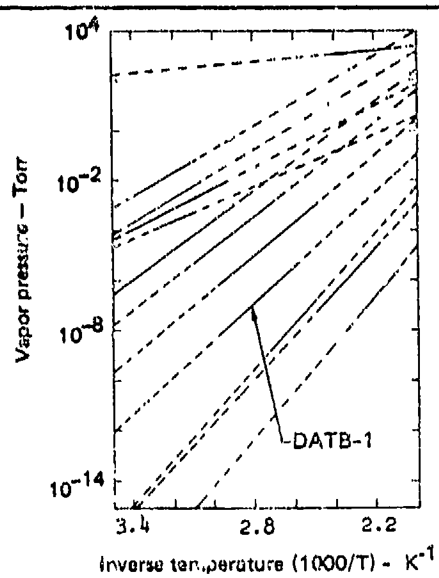
Creep

Failure envelope

NOTES



DTA (—) and pyrolysis (--) curves

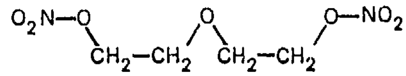


Vapor pressure vs 1/T

EXPLOSIVE: 2,2'-OXYBISETHANOL, DINITRATE

DESIGNATION: **DEGN**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: liquid

Color: clear

At. comp.: $C_4H_8N_2O_7$

MW: 196

Density (g/cm^3): TMD: 1.39

Nominal:

m.p. (°C (K)):

b.p. (°C (K)): 160-161 (433-434)

v.p. (mm Hg (Pa)): 0.00593 at 25°C(0.789 at 298 K)

Crystal data:

R:

n = 1.450

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:		
Exp:		

ΔH_f (kcal/mol (kJ/mol)): -99.4 (-416)

Solubility (s-sol., sl-sl. sol., i-insol.):

sl - water, alcohol

i - acetone, ethyl ether

6. THERMAL PROPERTIES

λ:

CTE:

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr:

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 6.76 (ρ= 1.38)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.:

Calc.:

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm:

19 mm:

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool

Susan test:

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event

Gap test (mils (mm)): (ρ=)

10. ELECTRICAL PROPERTIES:

ϵ:

11. TOXICITY

Moderate

DEGN

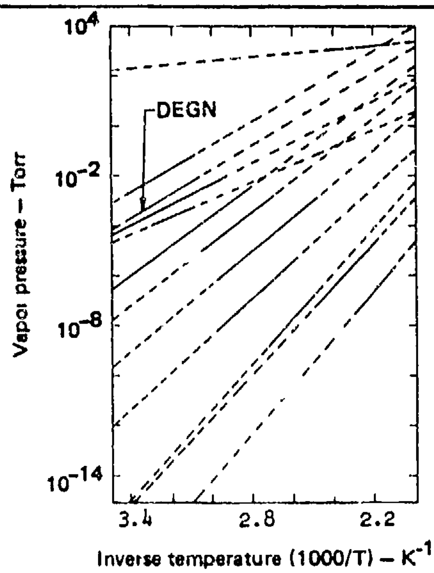
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

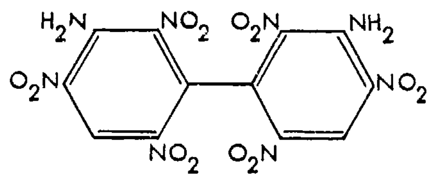


Vapor pressure vs 1/T

EXPLOSIVE: 2,2',4,4',6,6'-HEXANITRO-[1,1-BIPHENYL]-3,3'-DIAMINE

DESIGNATION: **DIPAM**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: --

At. comp.: $C_{12}H_6N_8O_{12}$

MW: 454.1

Density (g/cm^3): TMD: 1.79

Nominal: --

m.p. (°C (K)): 304 (577)

b.p. (°C (K)): --

v.p. (mm Hg (Pa)): --

Crystal data: --

R: --

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.35 (5.65)	1.27 (5.31)
Exp:	--	--

ΔH_f (kcal/mol (kJ/mol)): -6.8 (-28.45)

Solubility (s-sol., sl-sl. sol., i-insol.):
s - DMFA, DMSO, nitric acid
sl - acetone, chloroform

6. THERMAL PROPERTIES

λ: --

CTE: --

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):
Exp. 0.25 (1.05)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: --

1 g for 48 hr: --

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.40 (ρ= 1.76)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.: --

Calc.: --

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ=)

6 mm: --

19 mm: --

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.95	--
2.5 kg:	0.85	0.96

Susan test: --

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
--	--	

Gap test (mils (mm)): (ρ=)
NSWC-SSGT: (4.48) (ρ = 1.784)

10. ELECTRICAL PROPERTIES:

ϵ: --

11. TOXICITY

Moderate

DIPAM

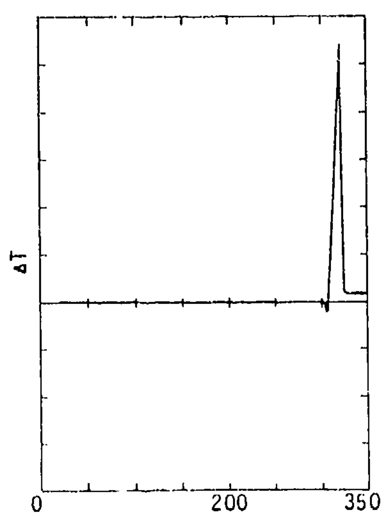
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

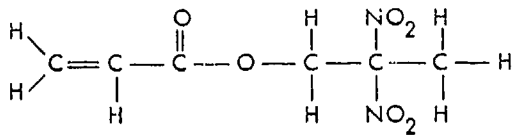


DTA curve

EXPLOSIVE: 2,2-DINITROPROPYL ACRYLATE

DESIGNATION: **DNPA**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: off-white

At. comp.: $C_6H_8N_2O_6$

MW: 204.1

Density (g/cm^3): TMD: 1.47

Nominal: —

m.p. (°C (K)): —

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.06 (4.44)	0.85 (3.57)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): -110 (-460)

Solubility (s-sol., sl-sl. sol., i-insol.):

s—acetone

6. THERMAL PROPERTIES

λ: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.04-0.06

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): — (ρ=)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.: —

Calc.: —

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	>1.77	—
2.5 kg:	--	--

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

—

DNPA

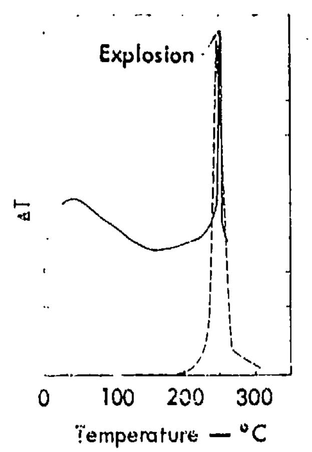
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

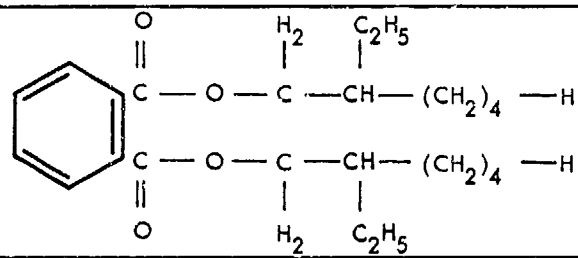
NOTES



DTA (—) and pyrolysis (--) curves

MATERIAL: DI-2-ETHYLHEXYL PHTHALATE (Plasticizer)	DESIGNATION : **DOP** SUPPLIER :

2. STRUCTURAL FORMULATION



4. PHYSICAL PROPERTIES

Physical state : liquid

Color : clear

At. comp. : $C_{24}H_{38}O_4$

MW : 390.6

Density (g/cm^3) : TMD : 0.986

Nominal : ——

m.p. (°C (K)) :

b.p. (°C (K)) : 222-230 (495-503)

v.p. (mm Hg (Pa)) : <0.06 at 150°C (<8.0 at 423 K)

Brittle point (°C (K)) :

f.p. (°C (K)) : -55 (218)

Crystal data :

R :

n : 1.485 at 25°C (298 K)

Shore hardness :

5. CHEMICAL PROPERTIES

ΔH_f (kcal/mol (kJ/mol)) : -268.2 (-1122)

Solubility (s-sol., sl-sl. sol., i-insol.) :

s – gasoline, mineral oil
i – glycerine, water

7. MECHANICAL PROPERTIES

Tensile strength (psi (kPa)):

Elongation (%) :

6. THERMAL PROPERTIES

λ :

CTE : 74 μm/m at 283-313 K

T_g (°F (K)) :

C_p (cal/g-°C (kJ/kg-K)) :
~0.57 at 50-150°C (~2.39 at 323-423 K)

10. ELECTRICAL PROPERTIES

ε : (ρ =

11. TOXICITY

Low

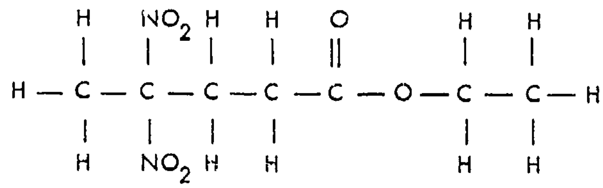
NOTES

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EXPLOSIVE: ETHYL 4,4-DINITROPENTANOATE

DESIGNATION: **EDNP**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: liquid

Color: yellow

At. comp.: $C_7H_{12}N_2O_6$

MW: 220.2

Density (g/cm^3): TMD: 1.28

Nominal: —

m.p. (°C (K)): -6 (268)

b.p. (°C (K)): 83 at 0.05 mm (356 at 6.7 Pa)

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.23 (5.15)	0.94 (3.93)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): -140 (-586)

Solubility (s-sol., sl-sl. sol., i-insol.):

s—acetone, carbon tetrachloride, chloroform, DMFA, DMSO, ethanol, ethyl acetate, ethyl ether, pyridine

i—water

6. THERMAL PROPERTIES

λ: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.04-0.06

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): — (ρ=)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.: —

Calc.: —

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
	>1.77	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

—

7/74

EDNP

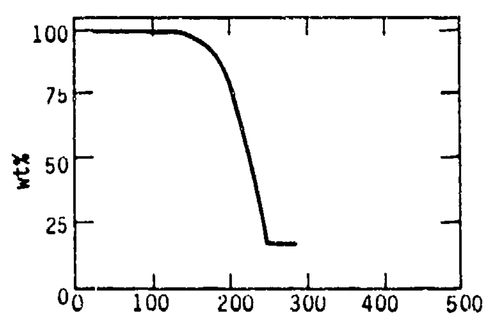
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES



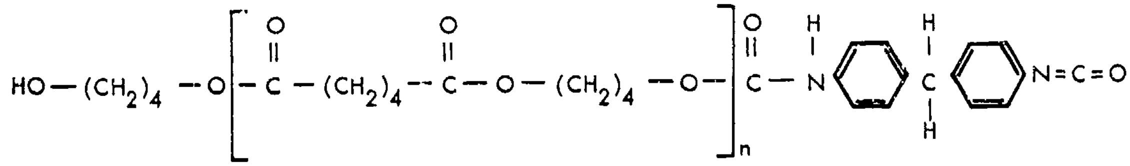
TGA curve

MATERIAL: POLYURETHANE SOLUTION SYSTEM (Binder)

DESIGNATION: **Estane**

SUPPLIER: B. F. Goodrich

2. STRUCTURAL FORMULATION



n = 5-10

4. PHYSICAL PROPERTIES

Physical state: rubbery solid

Color: light amber

At. comp.: $(C_{5.14}H_{7.50}N_{0.19}O_{1.76})_n$

MW: 100

Density (g/cm^3): TMD:

Nominal: 1.18

m.p. (°C (K)):

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

Brittle point (°C (K)):

f.p. (°C (K)):

Crystal data:

R:

n:

Shore hardness: A 70

5. CHEMICAL PROPERTIES

ΔH_f (kcal/100g(kJ/100g)): -95 (-397)

Solubility (s-sol., sl-sl. sol., i-insol.):

s – acetone, dichloroethane, DMFA, DMSO, MEK, MIBK, THF

7. MECHANICAL PROPERTIES

Tensile strength (psi (kPa)):

Elongation (%):

Sound velocity (km/s):	C_ℓ	C_s	C_b
(ρ = 1.18)	--	--	2.35

6. THERMAL PROPERTIES

λ: 5703: 3.53×10^{-4} cal/cm-sec-°C (0.148 W/m-K)

5702: (0.146 W/m·K)

CTE: 5702: $\beta \approx 600$ µm/m-K

5703: $\alpha \approx 245$ µm/m-K at 20-44°C

5703: $\beta \approx 600$ µm/m-K

T_g (°F (K)): -31 (242): (5702)

C_p (cal/g-°C (kJ/kg-K))	5702	5703
Exp.	(1.48 < Tg)	(1.56 < Tg)
	(1.71 > Tg)	(1.68 > Tg)

10. ELECTRICAL PROPERTIES

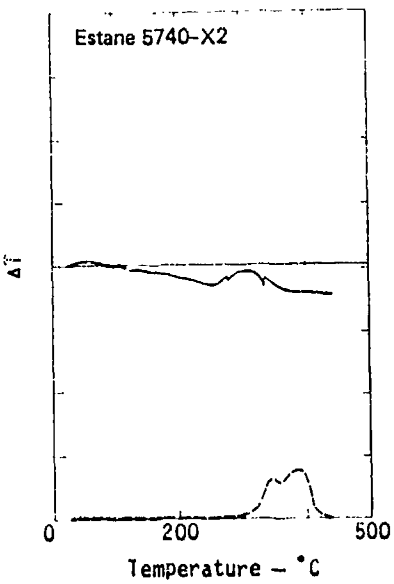
ϵ: (ρ =

11. TOXICITY

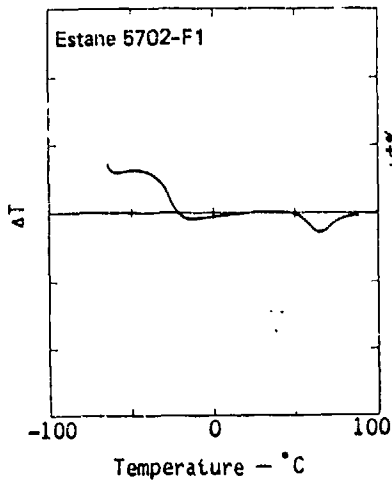
None.

NOTES

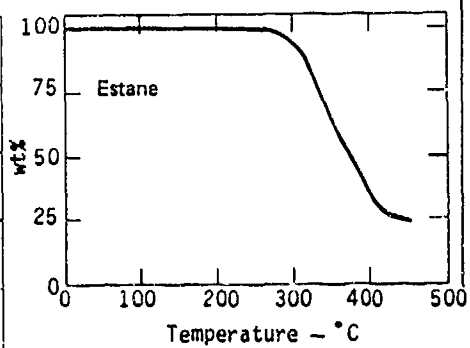
Estane



DTA (—) and pyrolysis (--) curves

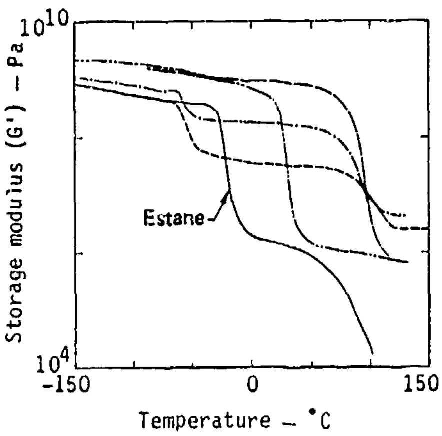


DSC curve



TGA curve

7. MECHANICAL PROPERTIES



Storage modulus

Explosive D

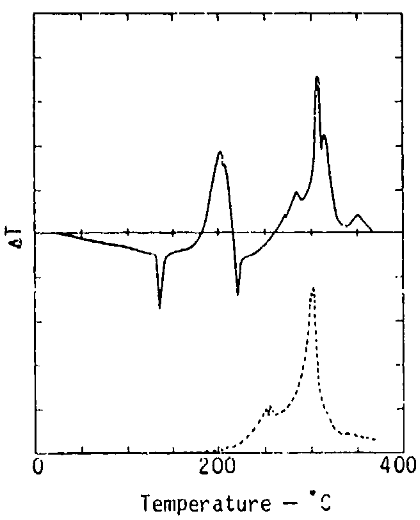
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

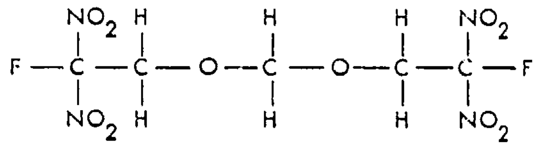
NOTES



DTA (—) and pyrolysis (--) curves

EXPLOSIVE: 1,1'-[METHYLENEBIS(OXY)] BIS [2-FLUORO-2,2-DINITROETHANE]	DESIGNATION: **FEFO**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: liquid

Color: straw

At. comp.: $C_5H_6N_4O_{10}F_2$

MW: 320.1

Density (g/cm^3): TMD: 1.607

Nominal: —

m.p. (°C (K)): 14.5 (287.5)

b.p. (°C (K)): 110 at 0.3 mm (383 at 40 Pa)

v.p. (mm Hg (Pa)): 2.14×10^{-4} at 25°C (2.85×10^{-2} at 298 K)

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.45 (6.07)	1.39 (5.82)
Exp:	1.28 (5.36)	1.21 (5.06)

ΔH_f (kcal/mol (kJ/mol)): -177.5 (-743)

Solubility (s-sol., sl-sl. sol., i-insol.):
- s—acetone, chloroform, DMFA, DMSO, ethanol, ethyl acetate, ethyl ether, pyridine
- i—carbon tetrachloride, water

6. THERMAL PROPERTIES

λ: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.36 at 25°C (1.51 at 298 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.04-0.10

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.50 (ρ= 1.607)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.59)

Meas.: 250

Calc.: 232

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.28	—
2.5 kg:	0.60	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (ρ=)

SRI-GT: (19.6)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

High.

1/85

FEFO

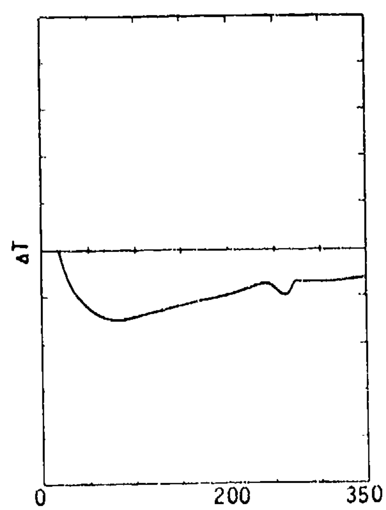
7. MECHANICAL PROPERTIES

Initial modulus

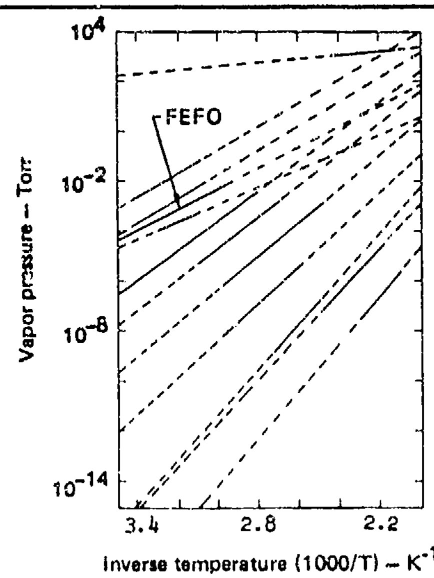
Creep

Failure envelope

NOTES



DTA curve



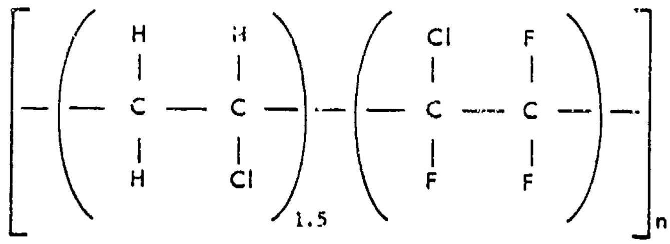
Vapor pressure vs 1/T

MATERIAL:
VINYL CHLORIDE/TRIFLUOROCHLOROETHYLENE COPOLYMER (Binder) 1.5:1

DESIGNATION : **FPC 461**

SUPPLIER : Hooker Chemical

2. STRUCTURAL FORMULATION



4. PHYSICAL PROPERTIES

Physical state : solid
Color : white
At. comp. : $(C_5H_{4.5}Cl_{2.5}F_3)_n$
MW : $(210)_n$
Density (g/cm^3) : TMD :
Nominal : 1.70
m.p. (°C (K)) :
b.p. (°C (K)) :
v.p. (mm Hg (Pa)) :
Brittle point (°C (K)) :
f.p. (°C (K)) :

Crystal data :

R :
n :
Shore hardness :

5. CHEMICAL PROPERTIES

ΔH_f (kcal/mol (kJ/mol)) : -190 (-795)

Solubility (s-sol., sl-sl. sol., i-insol.) :
s – gasoline, MEK, toluene, xylene

7. MECHANICAL PROPERTIES

Tensile strength (psi (kPa)):

Elongation (%) :

6. THERMAL PROPERTIES

λ :
CTE :

T_g (°F (K)) :
C_p (cal/g-°C (kJ/kg-K)) :

10. ELECTRICAL PROPERTIES

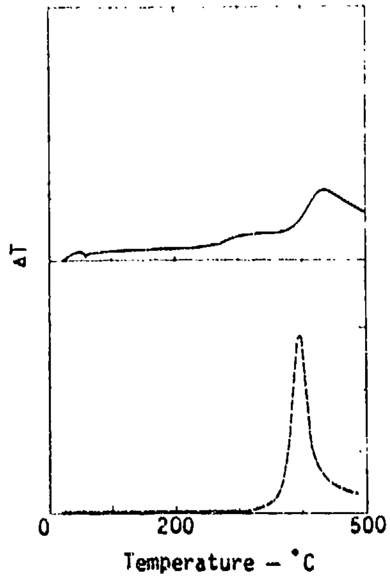
ε : 2.82 (ρ = 1.7)

11. TOXICITY

Low

NOTES

FPC 461



DTA (—) and pyrolysis (--) curves

EXPLOSIVE: H-6

DESIGNATION: **H-6**

2. STRUCTURE OR FORMULATION

	wt%
RDX	45
TNT	30
Al	20
D-2 wax	5
$CaCl_2$ added	0.5

4. PHYSICAL PROPERTIES

Physical state: solid

Color:

At. comp.: $C_{1.89}H_{2.59}N_{1.61}O_{2.01}Al_{0.74}Ca_{0.005}Cl_{0.009}$

MW: 100

Density (g/cm^3): TMD: 1.791

Nominal: 1.75

m.p. (°C (K)):
b.p. (°C (K)):
v.p. (mm Hg (Pa)):

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):

	H_2O (ℓ)	H_2O (g)
Calc:		
Exp:		

ΔH_f (kcal/100g (kJ/100g)): -1.75 (-7.31)

Solubility (s - sol., sl - sl. sol., i - insol.):

6. THERMAL PROPERTIES

λ: 11.0 × 10^{-4} cal/cm-sec-°C (0.460 W/m-K) at 308 K

CTE: α = 149 μm/m-K at 308 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):
Exp. 0.269 at 30°C (1.13 at 303 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: 0.096

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.9 (ρ= 1.75)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.:

Calc.:

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.76)

6 mm: 0.769

19 mm: 1.066

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.60	--
2.5 kg:	--	--

Susan test: Difficult to ignite by mechanical means; once ignited, low probability for buildup to violent reaction at light confinement.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event

Gap test (mils (mm)): (ρ=)

NSWC-SSGT: (4.85) (ρ = 1.708)

10. ELECTRICAL PROPERTIES:

ϵ :

11. TOXICITY

H-6

7. MECHANICAL PROPERTIES

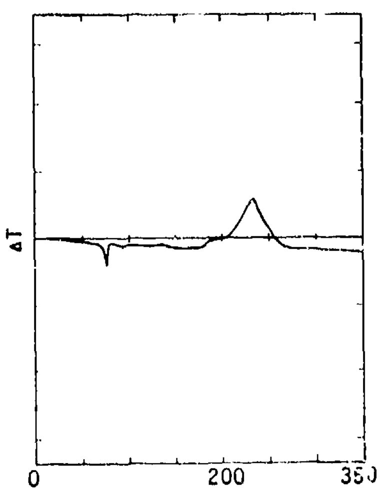
Sound velocity (km/s):	C_ℓ	C_s	C_b
(ρ = 1.75)	2.46	1.55	--

Initial modulus

Creep

Failure envelope

NOTES



DTA curve

EXPLOSIVE: HBX-1 HBX-3	DESIGNATION: HBX

2. STRUCTURE OR FORMULATION

	wt%	
	HBX-1	HBX-3
RDX	40	31
TNT	38	29
Al	17	35
D-2 wax	5	5
$CaCl_2$ added	0.5	0.5

4. PHYSICAL PROPERTIES

Physical state: solid

Color: gray

At. comp.:

MW: 100

Density (g/cm^3): TMD: 1.76 1.882

Nominal: 1.71 cast 1.84-1.85
1.74 pressed

m.p. (°C (K)):
b.p. (°C (K)):
v.p. (mm Hg (Pa)):

HBX-1: $C_{2.06}H_{2.62}N_{1.57}O_{2.07}Al_{0.63}Ca_{0.005}Cl_{0.009}$

HBX-3: $C_{1.66}H_{2.18}N_{1.21}O_{1.60}Al_{1.27}Ca_{0.005}Cl_{0.009}$

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):		H_2O (ℓ)	H_2O (g)
HBX-1:	Calc:	1.84 (7.7)	1.8 (7.53)
HBX-3:	Exp: Calc:	2.11 (8.83)	2.11 (8.83)

ΔH_f (kcal/100g (kJ/100g)): HBX-1: -2.64 (-11.04)
HBX-3: -2.60 (-10.89)

Solubility (s-sol., sl-sl. sol., i-insol.):

6. THERMAL PROPERTIES

λ: HBX-1: 9.7×10^{-4} cal/cm-sec-°C (0.406 W/m-K) at 308 K

HBX-3: 17.0×10^{-4} cal/cm-sec-°C (0.711 W/m-K) at 308 K

CTE: HBX-1: α = 171 µm/m-K at 308 K
HBX-3: α = 149 µm/m-K at 308 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):
HBX-1: Exp. 0.249 at 30°C (1.04 at 303 K)
HBX-3: Exp. 0.254 at 30°C (1.06 at 303 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr:

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/µsec (km/s)): (1) 7.31 (ρ = 1.712)
(3) 7.12 (ρ = 1.84)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.712)

Meas.: HBX-1: 220.4

Calc.:

E_{cyl} ((mm/µsec)^2/2 (MJ/kg)): (ρ =)

6 mm:

19 mm:

9. SENSITIVITY

H_{50} (m): 12 tool 12B tool

Susan test:

Skid test:
Impact angle (deg (rad)) Drop ht. (ft (m)) Event

Gap test (mils (mm)): (ρ =)
HBX-3: NSWC-SSGT: (2.57) (ρ = 1.827)

10. ELECTRICAL PROPERTIES:

ε:

11. TOXICITY

HBX

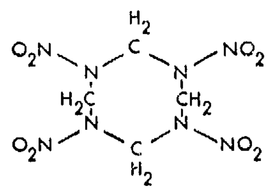
7. MECHANICAL PROPERTIES

Initial modulus	Failure envelope
Creep	

NOTES

EXPLOSIVE: OCTAHYDRO-1,3,5,7-TETRANITRO-1,3,5,7-TETRAZOCINE	DESIGNATION: **HMX**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_4H_8N_8O_8$

MW: 296.2

Density (g/cm^3): TMD: 1.905

Nominal:

m.p. (°C (K)): 285 (558)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): 3×10^{-9} at 100°C

(4×10^{-7} at 373 K)

Crystal data:

I: monoclin. ($P2_1/c$)	II: orthorh. (Fdd2)	III: monoclin. (Pc_1P2/c)	IV: hexag. ($P6_122$)
a = 6.54	a = 15.14	a = 10.95	a = 7.71
b = 11.05	b = 23.89	b = 7.93	
c = 8.70	c = 5.91	c = 14.61	c = 32.55
β = 124.3		β = 119.4	

R: I: 58 calc., 56.1 obs.; II: 58 calc., 55.7 obs.; III: 58 calc., 55.4 obs.; IV: 58 calc., 55.9 obs.

n: See Table 4-3.

5. CHEMICAL PROPERTIES

Δ H_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.62 (6.78)	1.48 (6.19)
Exp:	1.48 (6.19)	1.37 (5.73)

Δ H_f (kcal/mol (kJ/mol)): +17.93 (+75)

Solubility (s-sol., sl-sl. sol., i-insol.):

solvate — DMFA, DMSO, butyrolactone

sl — acetone, pyridine

i — carbon disulfide, carbon tetrachloride, chloroform, ethyl ether, water

6. THERMAL PROPERTIES

λ: $12.2\text{-}13.3 \times 10^{-4}$ cal/cm-sec-°C (0.511-0.556 W/m-K) at RT

CTE: α = 22.0 μ in./in.-°F at -65 to 165°F

(α = 50.4 μm/m-K at 219-347 K)

β = 162.5 μm/m-K at 243-343 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): none

C_p (cal/g-°C (kJ/kg-K)):

See Fig. 6-4

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: < 0.01

1 g for 48 hr: 0.07

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 9.11 (ρ = 1.89)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.89)

Meas.: 390

Calc.: 394

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ = 1.894)

6 mm: 1.410

19 mm: 1.745

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.33	0.40
2.5 kg:	0.32	0.30

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):

NSWC-SSGT:	(8.71)	(ρ = [illegible])
LANL-SSGT:	(3.43)	(ρ = 1.040)
LANL-LSGT:	2.783 (70.7)	(ρ = 1.07)

10. ELECTRICAL PROPERTIES:

ε:	I: 3.087	(ρ = 1.90)
	II: 4.671	(ρ = 1.87)
	III: 3.867	(ρ = 1.82)

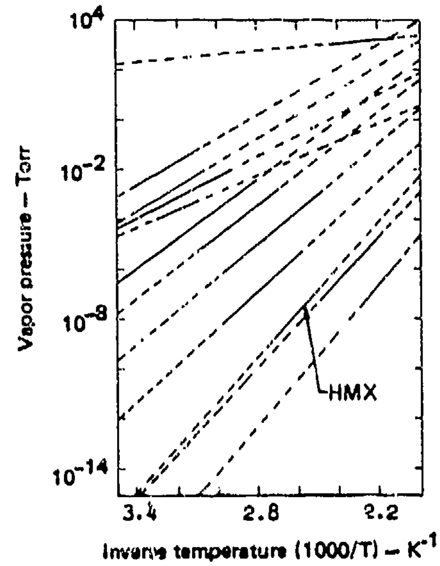
11. TOXICITY

Low

7. MECHANICAL PROPERTIES

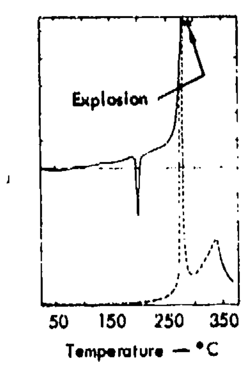
Initial modulus

Creep

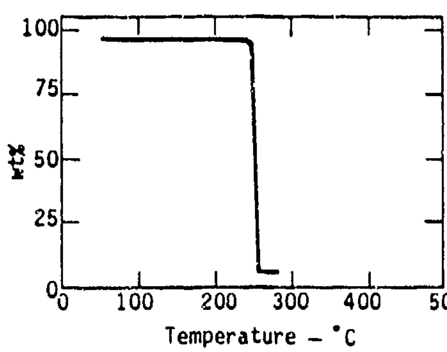


Vapor pressure vs 1/T

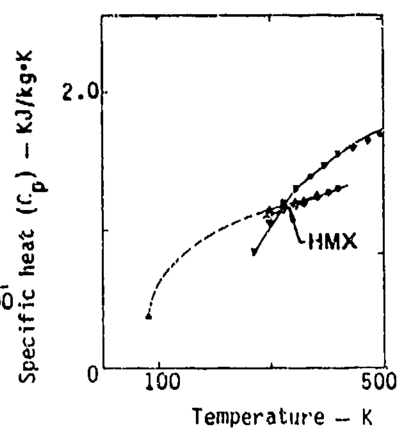
NOTES



DTA (—) and pyrolysis (--) curves



TGA curve

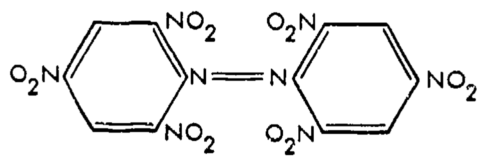


Specific heat vs T

EXPLOSIVE: BIS(2,4,6-TRINITROPHENYL)-DIAZINE

DESIGNATION: **HNAB**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: reddish-orange

At. comp.: $C_{12}H_4N_8O_{12}$

MW: 452.2

Density (g/cm^3): TMD: I: 1.799
II: 1.750

m.p. (°C (K)): 220(493)
b.p. (°C (K)): —
v.p. (mm Hg (Pa)): 1×10^{-7} at 100°C
(1.33×10^{-5} at 373 K)

Crystal data: Monoclinic

I: ($P2_1/c$)	II: ($P2_1/a$)
a = 10.15	a = 10.63
b = 8.26	b = 21.87
c = 10.06	c = 7.59
β = 97.3	β = 102.6

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.47 (6.15)	1.42 (5.94)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): +67.9 (+284.1)

Solubility (s-sol., sl-sl. sol., i-insol.):
s--acetone, butyrolactone, DMFA, DMSO, ethyl acetate N-methylpyrrolidone, pyridine
sl--chloroform, benzene, ethanol, sulfuric acid, water
i--carbon tetrachloride, ethyl ether

6. THERMAL PROPERTIES

λ: —

CTE: α = 80 μm/m-K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est. 0.3 (1.25)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.311 (ρ= 1.60)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.60)

Meas.: 205

Calc.: —

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	—	—
2.5 kg:	0.37	0.32

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (ρ=)

NSWC-SSGT:	(6.38)	(ρ = 1.774)
LANL-SSGT:	219 (5.6)	(ρ = 1.601)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

Low

3/81

7. MECHANICAL PROPERTIES

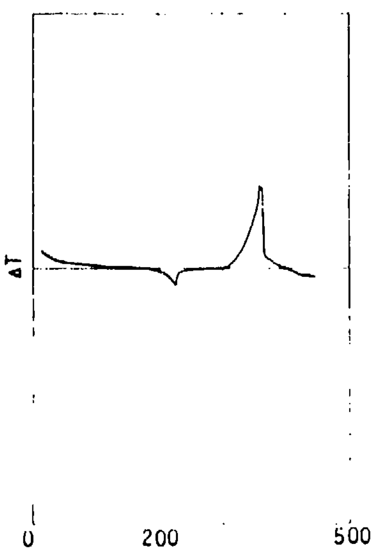
Sound velocity (km/s):	C_ℓ	C_s	C_b
(ρ = 1.577)	0.853	0.465	0.663

Initial modulus

Creep

Failure envelope

NOTES

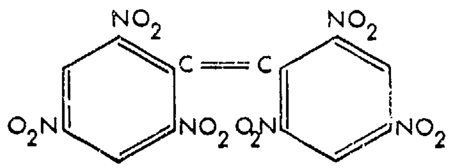


DTA curve

EXPLOSIVE: 1,1'-(1,2-ETHENEDIYL)BIS-(2,4,6-TRINITROBENZENE)

DESIGNATION: **HNS**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: yellow

At. comp.: $C_{14}H_6N_6O_{12}$

MW: 450.3

Density (g/cm^3): TMD: 1.740

Nominal: 1.72

m.p. (°C (K)): I: 315-316 (588-589) with dec.; II: 318 (591)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)):

II: 1×10^{-9} at 100°C (1.33×10^{-7} at 373 K)

Crystal data: monoclinic $P2_1/c$

a = 22.13
b = 5.57
c = 14.67
β = 108.4

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.42 (5.94)	1.36 (5.69)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): +18.7 (+78.24)

Solubility (s-sol., sl-sl. sol., i-insol.):

sl--butyrolactone, DMFA, DMSO, N-methylpyrrolidone
i--acetone

6. THERMAL PROPERTIES

λ: I: 2.04×10^{-4} cal/cm-sec-°C (0.085 W/m-K) at 293 K

II: 1.91×10^{-4} cal/cm-sec-°C (0.080 W/m-K) at 293 K

CTE: α = 92 μm/m-K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.40 (1.67)
Exp.: 0.23 (0.962)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.01

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): I: 6.80 (ρ = 1.60)
II: 7.00 (ρ = 1.70)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.60)

Meas.: —

Calc.: 200

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ =)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	—	—
2.5 kg:	0.54	0.66

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (ρ =)

I:	NSWC-SSGT:		(5.18)	(ρ = 1.694)
II:	NSWC-SSGT:		(5.46)	(ρ = 1.725)
I:	LANL-SSGT:	208	(5.28)	(ρ = 1.669)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

Low

HNS

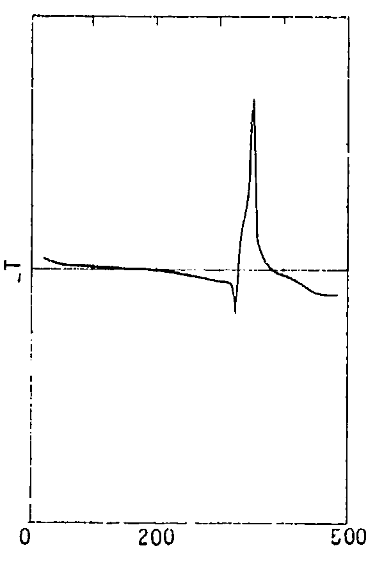
7. MECHANICAL PROPERTIES

Initial modulus

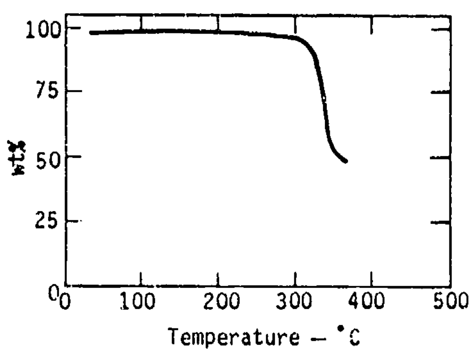
Creep

Failure envelope

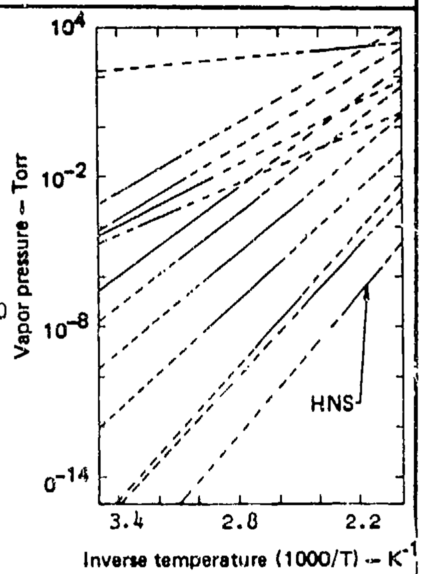
NOTES



DTA curve



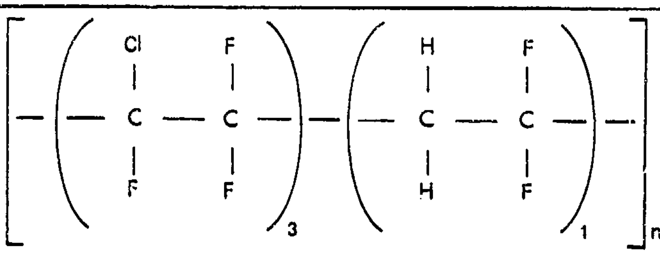
TGA curve



Vapor pressure vs 1/T

MATERIAL: CHLOROTRIFLUOROETHYLENE/VINYLIDINE FLUORIDE COPOLYMER 3:1 (Binder)	DESIGNATION: **Kel-F-800** SUPPLIER: 3 M

2. STRUCTURAL FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid
Color: off-white
At. comp.: $(C_8H_2Cl_3F_{11})_n$
MW: $(413.5)_n$
Density (g/cm^3): TMD:
Nominal: 2.02
m.p. (°C (K)):
b.p. (°C (K)):
v.p. (mm Hg (Pa)):
Brittle point (°C (K)):
f.p. (°C (K)):

Crystal data:

R:
n: 1.46
Shore hardness: D 64

5. CHEMICAL PROPERTIES

ΔH_f (kcal/mol (kJ/mol)): -578(-2418)

Solubility (s-sol., sl-sl. sol., i-insol.):
s - acetone, butyl acetate, ethyl acetate, MEK, MIBK, THF
i - toluene

7. MECHANICAL PROPERTIES

Tensile strength (psi (kPa)): 350-600 (2.41-4.14)

Elongation (%): 350

Sound velocity (km/s):	C_ℓ	C_s	C_b
(ρ = 2.02)	--	--	1.50

6. THERMAL PROPERTIES

λ: 1.26×10^{-4} cal/cm-sec-°C (0.053 W/m-K) at 314.4 K
CTE:
α = 60-105 µm/m-K < Tg
= 300-1600 µm/m-K > Tg
$\beta \simeq$ 700 µm/m-K

T_g (°F (K)): (301-311)

C_p (cal/g-°c (kJ/kg-K)): Exp. 0.239 < Tg (1.004 < Tg)

10. ELECTRICAL PROPERTIES

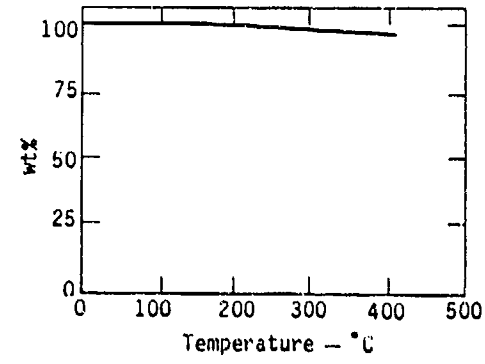
ϵ: 3.00 (ρ = 2.02)

11. TOXICITY

NOTES

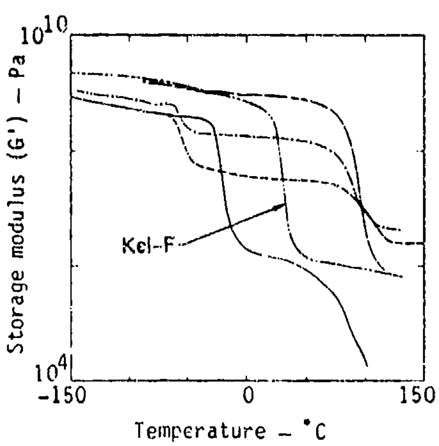
1/85

Kel-F - 800



TGA curve

7. MECHANICAL PROPERTIES



Storage modulus

EXPLOSIVE: LEAD AZIDE

DESIGNATION: **Lead azide**

2. STRUCTURE OR FORMULATION

$[N=N=N]^- Pb^{++} [N=N=N]^-$

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white-buff

At. comp.: $Pb(N_3)_2$

MW: 291

Density (g/cm^3): TMD: 4.80

Nominal: 4.38 dextrin.

m.p. (°C (K)): dec.

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

Crystal data:

α Orthorhombic (Pnma)	β Monoclinic (C2/m)
a = 6.63	a = 18.49
b = 16.25	b = 8.84
c = 11.31	c = 5.12
	β = 107.4

R: 35.1 obs.

n: see Table 4-3.

5. CHEMICAL PROPERTIES

Δ H_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	0.367 (1.54)	0.367 (1.54)
Exp:		

Δ H_f (kcal/mol (kJ/mol)): +112 (+469)

Solubility (s-sol., sl-sl. sol., i-insol.):

i--water

6. THERMAL PROPERTIES

λ: 4.2×10^{-4} cal/cm-sec-°C (0.176 W/m-K)

CTE: a axis: α = 76.9; b axis: α = 3.4; c axis: α = 18.3 } μm/m-K at 286 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):
Exp. 0.09 (0.377)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr:

1 g for 48 hr: <0.4

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 5.5 (ρ = 3.8)

P_{CJ} (kbar (10^{-1} GPa)): (ρ =)

Meas.:

Calc.:

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ =)

6 mm:

19 mm:

9. SENSITIVITY

H_{50} (m): 12 tool 12B tool

Susan test:

Skid test:

Impact angle (deg (rad)) Drop ht. (ft (m)) Event

Gap test (mils (mm)): (ρ =)

NSWC-SSGT: (2723) (ρ = 3.663)

10. ELECTRICAL PROPERTIES:

ε: a axis: 17 (ρ ~ 4.7); b axis: 120; c axis: 40

11. TOXICITY

High

Lead azide

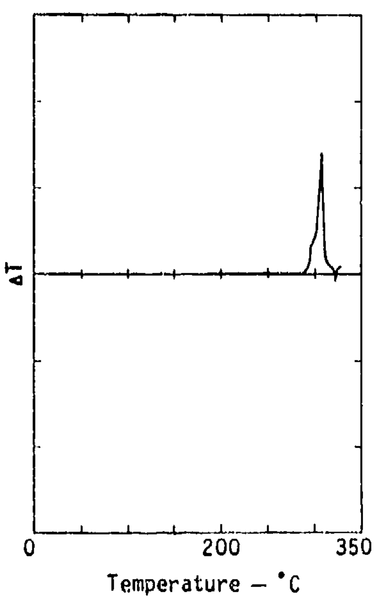
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

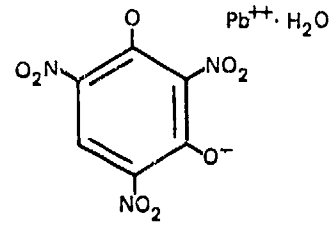


DTA curve

EXPLOSIVE: 2,4,6-TRINITRO-1,3-BENZENEDIOL, LEAD SALT

DESIGNATION: **Lead styphnate**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: orange-reddish brown

At. comp.: $C_6H_3N_3O_9Pb$

MW: 468.3

Density (g/cm^3): TMD: 3.02

Nominal: 2.63

m.p. (°C (K)): explodes 260-310 (533-583)

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

Crystal data: monoclinic
a = 10.06
b = 12.58
c = 8.05
β = 91.9

R: 73.9 obs.

n: see Table 4-3.

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	0.457 (1.91)	0.457 (1.91)
Exp:		

ΔH_f (kcal/mol (kJ/mol)): -200.0 (-837)

Solubility (s-sol., sl-sl. sol., i-insol.):

i--water, ether, $CHCl_3$, benzene, toluene
sl--acetone, ethanol

6. THERMAL PROPERTIES

λ:

CTE:

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr:

1 g for 48 hr: <0.4

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 5.2 (ρ= 2.9)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.:

Calc.:

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm:

19 mm:

9. SENSITIVITY

H_{50} (m): 12 tool 12B tool

Susan test:

Skid test:

Impact angle (deg (rad)) Drop ht. (ft (m)) Event

Gap test (mils (mm)): (ρ=)

10. ELECTRICAL PROPERTIES:

ε:

11. TOXICITY

Lead styphnate

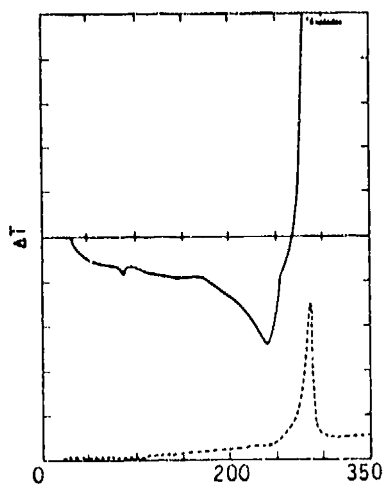
7. MECHANICAL PROPERTIES

Initial modulus

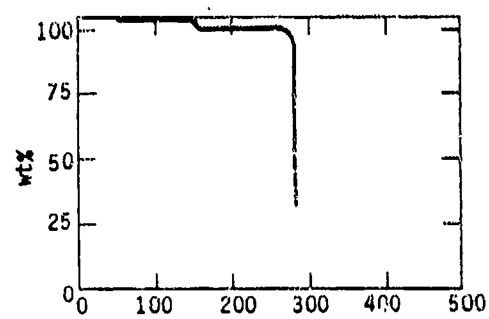
Creep

Failure envelope

NOTES



Temperature — °C
DTA (—) and pyrolysis (---) curves



Temperature — °C
TGA curve

EXPLOSIVE: LX-01

DESIGNATION: **LX-01**

2. STRUCTURE OR FORMULATION

	wt%
NM	51.7
TNM	33.2
1-Nitropropane	15.1

4. PHYSICAL PROPERTIES

Physical state: liquid

Color: clear

At. comp.: $C_{1.52}H_{3.73}N_{1.69}O_{3.39}$

MW:

Density (g/cm^3): TMD: 1.23

Nominal: —

m.p. (°C (K)): -54 (219)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): 29.0 at 25°C (3866 at 298 K)

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.72 (7.20)	1.52 (6.36)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): -27.5 (-115.2)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

λ: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 1.8 at 80°C (353)

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 6.84 (ρ= 1.24)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.31)

Meas.: 156

Calc.: 177

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
	—	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

—

3/81

7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

EXPLOSIVE: LX-02-1

DESIGNATION: **LX-02**

2. STRUCTURE OR FORMULATION

	wt%
PETN	73.5
Butyl rubber	17.6
Acetyltributyl citrate	6.9
Cab-O-Sil	2.0

4. PHYSICAL PROPERTIES

Physical state: puttylike solid

Color: buff

At. comp.: $C_{2.77}H_{4.86}N_{0.93}O_{2.99}Si_{0.03}$

MW:

Density (g/cm^3): TMD: 1.44

Nominal: 1.43-1.44

m.p. (°C (K)): no fixed m.p.

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.42 (5.94)	1.16 (4.85)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): -49.1 (-205.3)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

λ: —

CTE: α = 128.7 μm/m-K at 244-253 K

β = 385 μm/m-K at 243-343 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): none above -4 (253)

C_p (cal/g-°C (kJ/kg-K)):

Est.: 0.29 (1.21)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.3-0.6

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.37 (ρ= 1.44)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.: —

Calc.: —

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.80	—
2.5 kg:	--	--

Susan test: Very difficult to ignite; small probability of building to a violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

—

LX-02

7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

EXPLOSIVE: LX-04-1

DESIGNATION: **LX-04**

2. STRUCTURE OR FORMULATION

	wt%
HMX	85
Viton A	15

4. PHYSICAL PROPERTIES

Physical state: solid

Color: yellow

At. comp.: $C_{1.55}H_{2.58}N_{2.30}O_{2.30}F_{0.52}$

MW:

Density (g/cm^3): TMD: 1.889

Nominal: 1.86-1.87

m.p. (°C (K)): dec. >250 (>523)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.42 (5.94)	1.31 (5.49)
Exp:	1.31 (5.49)	1.25 (5.23)

ΔH_f (kcal/mol (kJ/mol)): -21.5 (-90.1)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

λ: 10.7×10^{-4} cal/cm-sec-°C; (0.448 W/m-K) at 293 K

CTE:

α = 28.5 μin./in.-°F at -65 to -18°F
(51.3 μm/m-K at 219-245 K)

α = 39.5 μin./in.-°F at -18 to 165°F
(71.1 μm/m-K at 245-347 K)

β = 228.2 μm/m-K at 243-343 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): -18 (245)

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.01-0.04

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.46 (ρ= 1.86)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.865)

Meas.: 350

Calc.: 330

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ = 1.865)

6 mm: 1.170

19 mm: 1.470

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.41	0.55
2.5 kg:	--	--

Susan test: Threshold velocity 140-150 ft/sec (43-46 m/s); moderately easy to ignite; low probability of building to a violent reaction. Some geometries detonate high-order.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	2.5 (0.76)	2
45 (0.79)	3.5 (1.07)	1

Gap test (mils (mm)):

NSWC-SSGT:	LX-04-0	(6.10)	(ρ = 1.828)
LANL-SSGT:	LX-04-1		(ρ = 1.865)
Pre-1965:	60-80	(1.5-2.0)	
Post-1965:	40-60	(1.0-1.5)	
LANL-SSGT:	LX-04-0	(2.31)	(ρ = 1.840)
LANL-LSGT:	LX-04-1	(51.71)	(ρ = 1.855)
PX-GT:		(20.3)	(ρ = 1.86)

10. ELECTRICAL PROPERTIES:

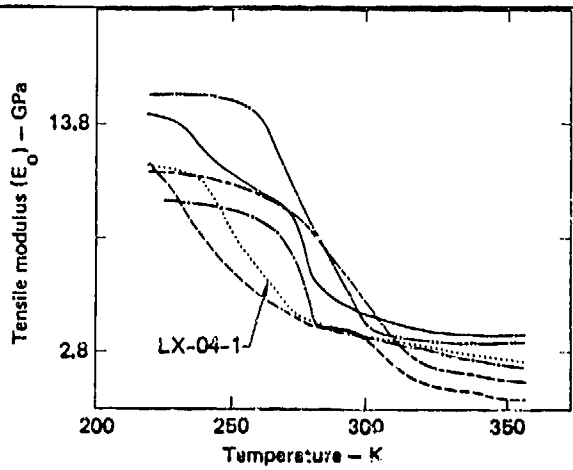
ε: 3.44 (ρ = 1.86)

11. TOXICITY

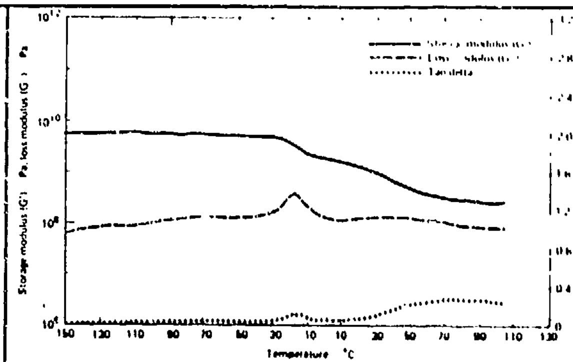
—

3/81

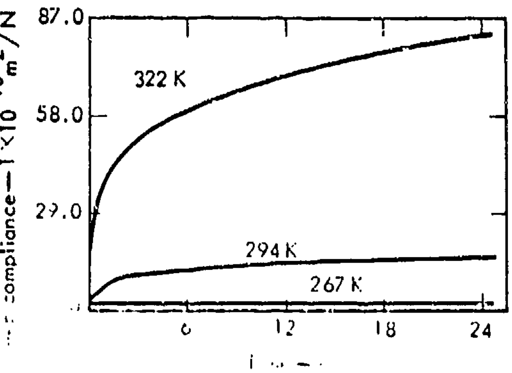
7. MECHANICAL PROPERTIES



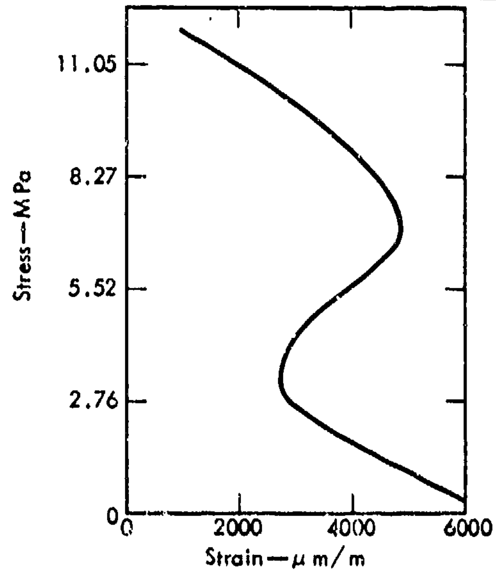
Initial modulus



Complex shear moduli

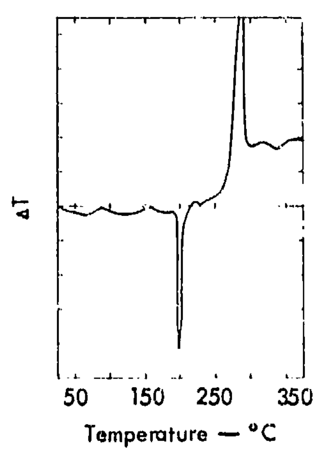


Creep

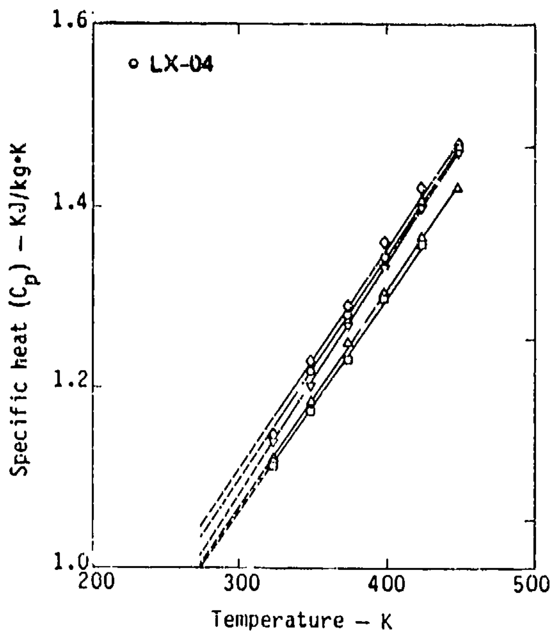


Failure envelope

NOTES



DTA (—) and pyrolysis (--) curves



Specific heat vs T

EXPLOSIVE: LX-07-2

DESIGNATION: **LX-07**

2. STRUCTURE OR FORMULATION

	wt%
HMX	90
Viton A	10

4. PHYSICAL PROPERTIES

Physical state: solid

Color: orange

At. comp.: $C_{1.48}H_{2.62}N_{2.43}O_{2.43}F_{0.35}$

MW:

Density (g/cm^3): TMD: 1.892

Nominal: 1.86 -1.87

m.p. (°C (K)): dec. >250 (>523)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.49 (6.23)	1.37 (5.73)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): -12.3 (-51.7)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

λ: 12.0×10^{-4} cal/cm-sec-°C (0.502 W/m-K) at 293 K

CTE:

α = 26.7 μin./in.- F at -65° to -18°F (48 μm/m-K at 219-245 K)

α = 34.8 μin./in.- F at -18° to 165°F (63 μm/m-K at 245-347 K)

β = 182.9 μm/m-K at 243-343 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): -18 (245)

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.01-0.04

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.64 (ρ = 1.87)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.865)

Meas.: —

Calc.: 346

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ = 1.857)

	LX-07-1
6 mm:	1.250
19 mm:	1.575

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.38	—
2.5 kg:	--	--

Susan test: Threshold velocity ~ 125 ft/sec (~ 38 m/s); has moderate buildup to violent reaction (LX-07-2).

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
*14 (0.24)	2.5 (0.76)	6
*45 (0.79)	7.1 (2.16)	5

*LX-07-1

Gap test (mils (mm)): (ρ = 1.857)

LANL-SSCT: 70-90 (1.8-2.3) (LX-07-1)

LANL-SSGT: 70-90 (1.8-2.3) (ρ = 1.859) (L-07-2)

10. ELECTRICAL PROPERTIES:

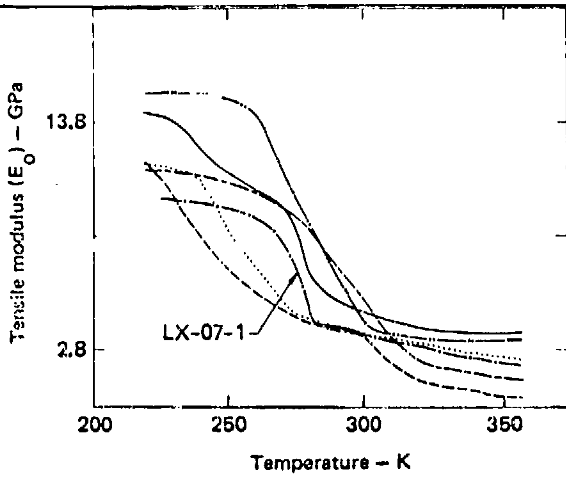
ε: —

11. TOXICITY

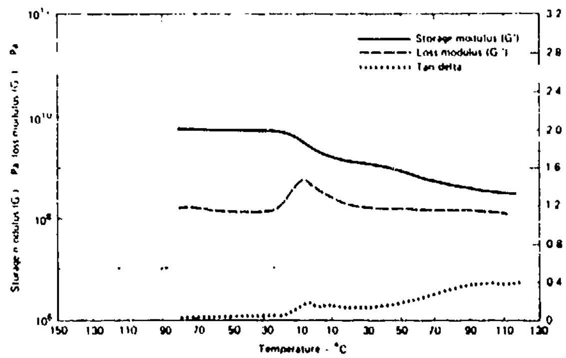
—

LX-07

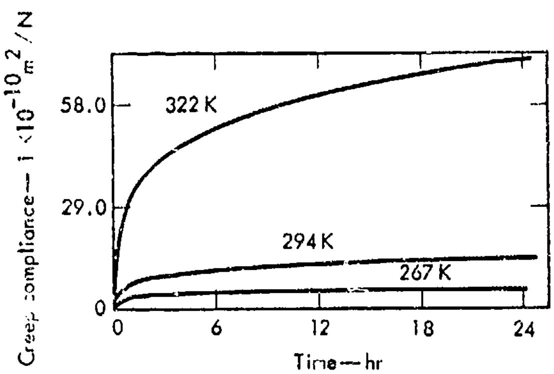
7. MECHANICAL PROPERTIES



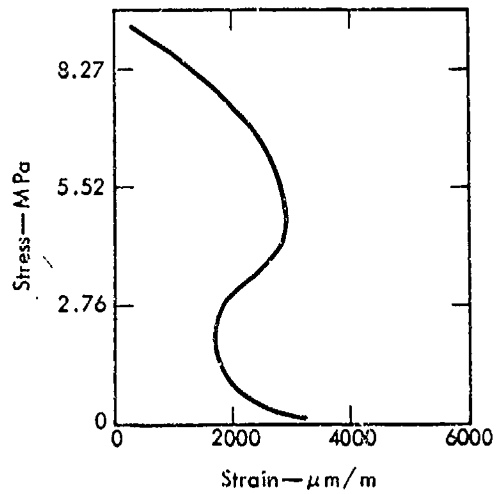
Initial modulus



Complex shear moduli

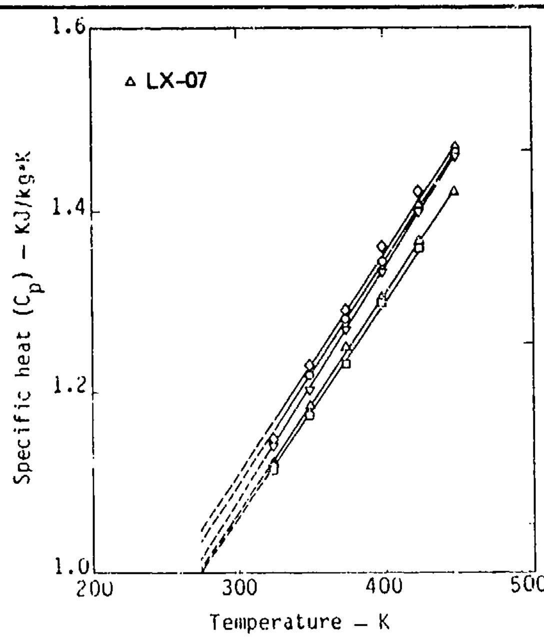


Creep



Failure envelope

NOTES



Specific heat vs T

EXPLOSIVE: LX-08-0

DESIGNATION: **LX-08**

2. STRUCTURE OR FORMULATION

	wt%
PETN	63.7
Sylgard	34.3
Cab-O-Sil	2.0

4. PHYSICAL PROPERTIES

Physical state: puttylike solid

Color: blue

At. comp.: $C_{1.93}H_{4.39}N_{0.81}O_{2.95}Si_{0.50}$

MW: 100

Density (g/cm^3): TMD: 1.439

Nominal: ≥1.42

m.p. (°C (K)): 129-135 (402-408) with dec.

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):

	H_2O (ℓ)	H_2O (g)
Calc:	1.98 (8.27)	1.77 (7.41)
Exp:	—	—

ΔH_f (kcal/100g (kJ/100g)): -44 (-184.1)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

λ: —

CTE:

α = 104.5 μin./in.-°F (188 m/m-K)

β = 565 μm/m-K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):

Est.: 0.28 (1.17)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 6.56 (ρ= ≥1.42)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.: —

Calc.: —

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ =)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):

		12 tool	12B tool
5 kg:	Cured	0.32	—
	Uncured	0.54	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event

Gap test (mils (mm)): (ρ=)

10. ELECTRICAL PROPERTIES:

ε : —

11. TOXICITY

—

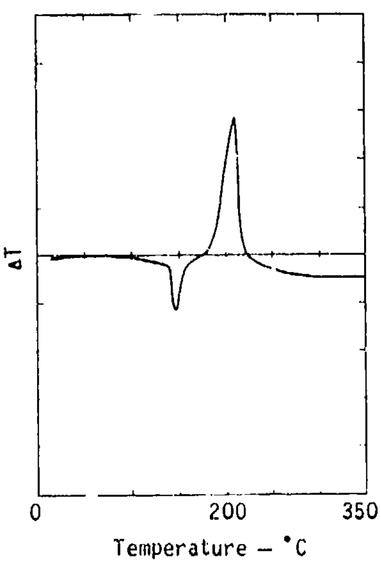
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES



DTA curve

EXPLOSIVE: LX-09-0, LX-09-1

DESIGNATION: **LX-09**

2. STRUCTURE OR FORMULATION

	wt%	
	LX-09-0	LX-09-1
HMX	93	93.3
pDNPA	4.6	4.4
FEFO	2.4	2.3

4. PHYSICAL PROPERTIES

Physical state: solid

Color: purple

At. comp.: $C_{1.43}H_{2.74}N_{2.59}O_{2.72}F_{0.02}$

MW:

Density (g/cm^3): TMD: 1.867

Nominal: 1.84–1.85

m.p. (°C (K)): dec. >280 (>253)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.60 (6.69)	1.46 (6.11)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): +1.82 (+7.61) (LX-09-0)
+2.004 (+8.38) (LX-09-1)

Solubility (s–sol., sl–sl. sol., i–insol.): —

6. THERMAL PROPERTIES

λ: 12.3×10^{-4} cal/cm-sec-°C (0.515 W/m-K) at 293 K

CTE:
α = 27.1 μin./in.-°F at -65 to -20°F
(48.8 μm/m-K at 219-244 K)
α = 31.0 μin./in.-°F at -20 to 165°F
(55.8 μm/m-K at 244-347 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): -20 (244)

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.03–0.07 LX-09-0

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): LX-09-1: 8.81 (ρ = 1.84)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.837)

Meas.: 377 } LX-09-0
Calc.: 373 }

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ = 1.836)

	LX-09-0
6 mm:	1.320
19 mm:	1.675

9. SENSITIVITY

H_{50} (m):		12 tool	12B tool
LX-09-0	5 kg:	0.32	—
	2.5 kg:	--	--

Susan test: Threshold velocity ~110 ft/sec (~34 m/s); has high probability of rapid buildup to violent reaction.

Skid test:

	Impact angle (deg (rad))	Drop ht. (ft (m))	Event
LX-09-0:	14 (0.24)	1.25 (0.38)	6
LX-09-0:	45 (0.79)	5.0 (1.52)	6

Gap test (mils (mm)):
LX-09-0: LANL-SSGT: 75-105 (1.9-2.7) (ρ = 1.835)
LX-09-0: LANL-LSGT: (58.47) (ρ = 1.834)

10. ELECTRICAL PROPERTIES:

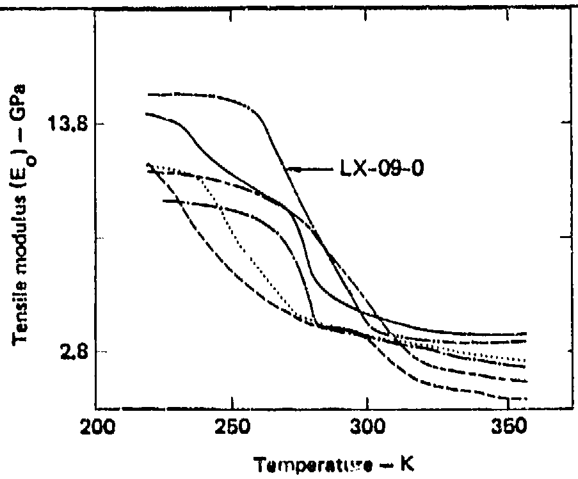
ε: —

11. TOXICITY

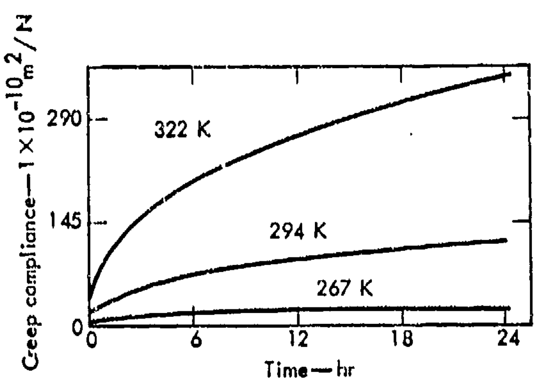
—

LX-09

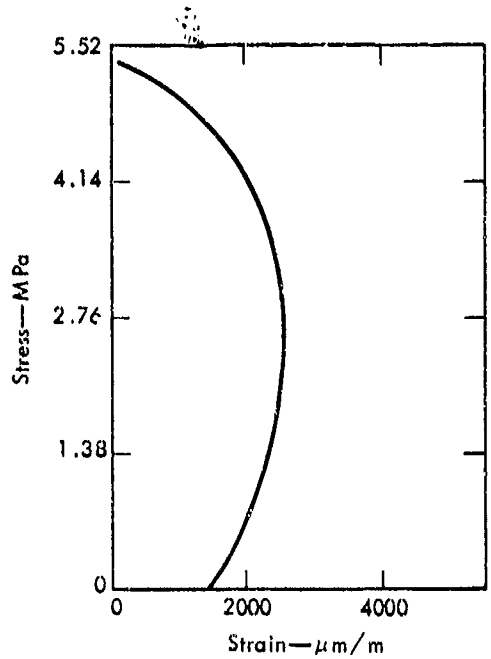
7. MECHANICAL PROPERTIES



Initial modulus

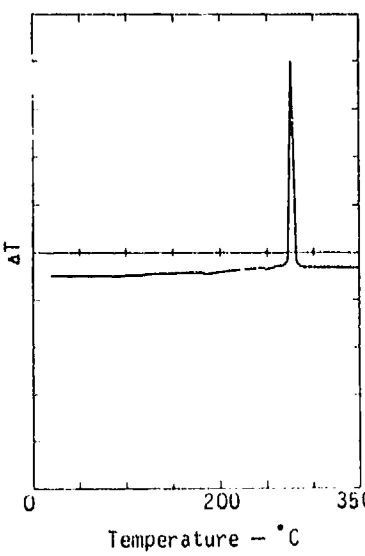


Creep

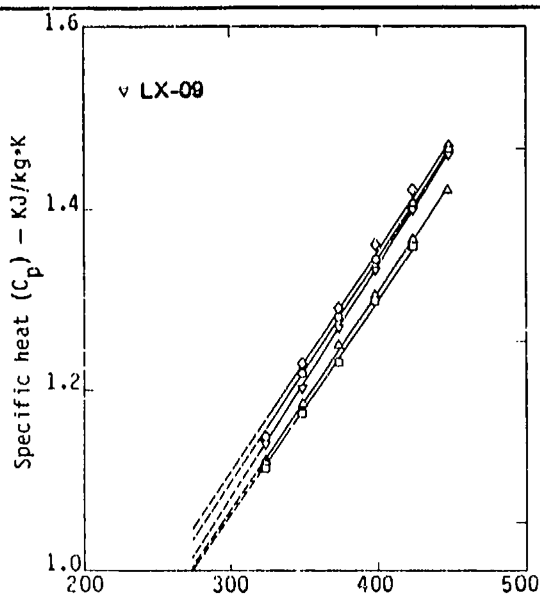


Failure envelope

NOTES



DTA curve



Specific heat vs T

EXPLOSIVE: LX-10-0, LX-10-1

DESIGNATION: **LX-10**

2. STRUCTURE OR FORMULATION

	wt% LX-10-0	wt% LX-10-1
HMX	95	94.5
Viton A	5	5.5

4. PHYSICAL PROPERTIES

Physical state: solid

Color: blue-green spots on , hite

At. comp.: LX-10-0: $C_{1.42}H_{2.66}N_{2.57}O_{2.57}F_{0.17}$

LX-10-1: $C_{1.410}H_{2.663}N_{2.579}O_{2.579}F_{0.156}$

MW: 100

Density (g/cm^3):

	LX-10-0	LX-10-1
TMD:	1.896	1.895
Nominal:	1.858-1.868	1.870

m.p. (°C (K)): dec. >250 (>523)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.55 (6.49)	1.4? (5.94)
Exp:	—	—

ΔH_f (kcal/100g(kJ/100g)): -3.14 (-13.1)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

λ: 12.3×10^{-4} cal/cm-sec-°C (0.515 W/m-K) at 293 K

CTE:

α = 24.8 μin./in.-°F at -65 to 0°F (44.6 μm/m-K at 219-255 K)

α = 26.2 μin./in.-°F at 0 to 165°F (47.0 μm/m-K at 255-347 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): -18 (245)

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

	LX-10-0	LX-10-1
0.25 g for 22 hr:	0.02	0.04-0.06
1 g for 48 hr:	—	

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): LX-10-0: 8.82 (ρ= 1.86)

LX-10-1: 8.85 (ρ = 1.87)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.860)

Meas.: 375

Calc.: 360

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ= 1.862)

6 mm: 1.315

19 mm: 1.670

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
LX-10-0 5 kg:	0.35	—
LX-10-0 2.5 kg:	0.40	—
LX-10-1 2.5 kg:	—	0.35

Susan test: Threshold velocity ~120 ft/sec (~37 m/s); has high probability of rapid buildup to violent reaction.

Skid test:

	Impact angle (deg (rad))	Drop ht. (ft (m))	Event
LX-10-0:	14 (0.24)	1.25 (0.38)	6
LX-10-0:	45 (0.79)	3.5 (1.07)	6
LX-10-1:	14 (0.24)	1.25 (0.38)	6
LX-10-1:	45 (0.24)	3.5 (1.07)	6

Gap test (mils (mm)): (ρ= 1.872)

LANL-SSGT: 80-100 (2.0-2.5)

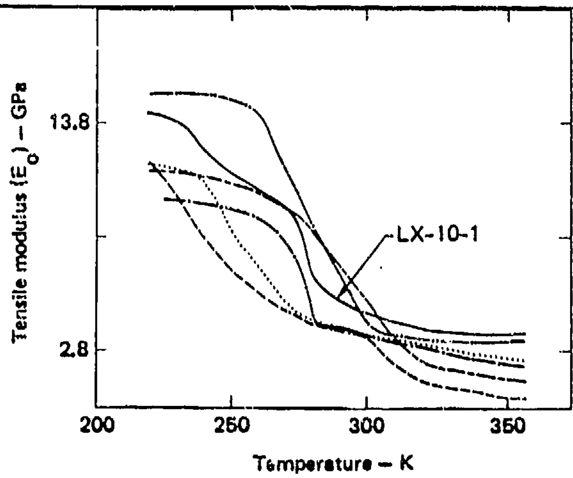
10. ELECTRICAL PROPERTIES:

ε: —

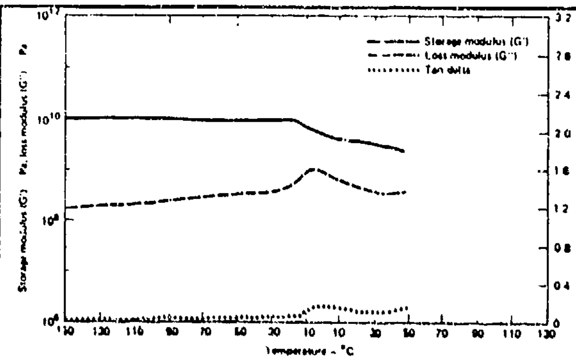
11. TOXICITY

—

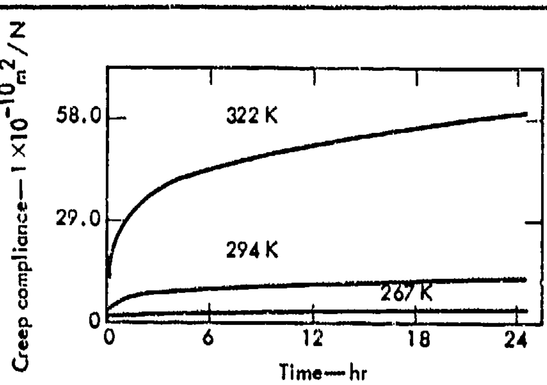
7. MECHANICAL PROPERTIES



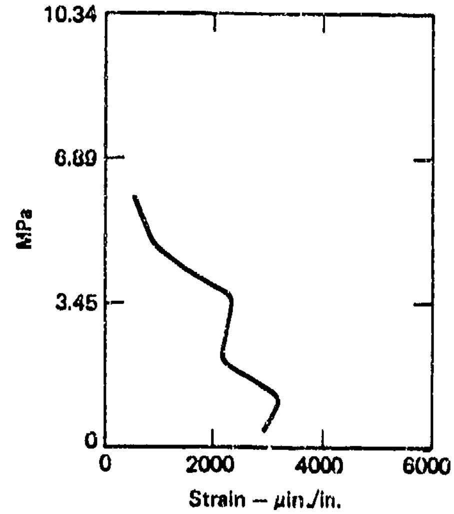
Initial modulus



Complex shear moduli

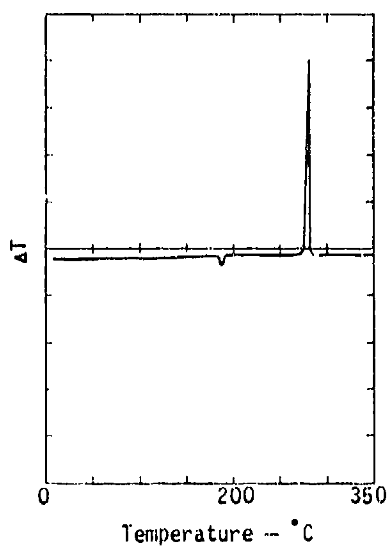


Creep

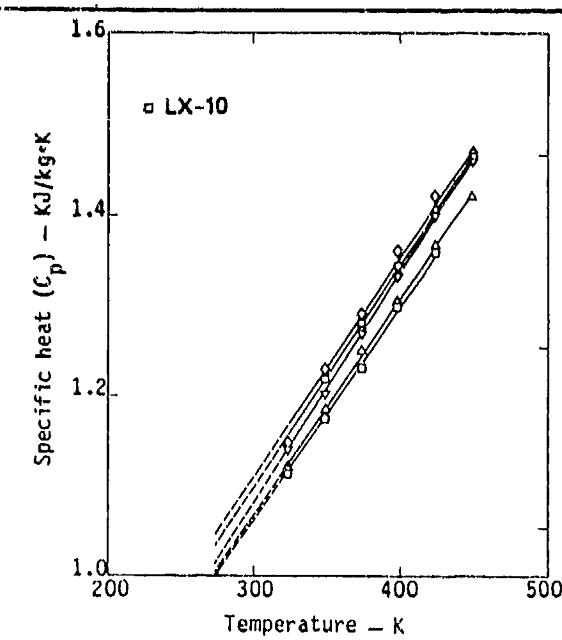


Failure envelope

NOTES



DTA curve



Specific heat vs T

EXPLOSIVE: LX-11-0

DESIGNATION: **LX-11**

2. STRUCTURE OR FORMULATION

	wt%
HMX	80
Viton A	20

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_{1.61}H_{2.53}N_{2.16}O_{2.16}F_{0.70}$

MW:

Density (g/cm³): TMD: —

Nominal: 1.87–1.88

m.p. (°C (K)): dec. >250 (>523)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.38 (5.77)	1.28 (5.36)
Exp:	1.12 (4.69)	1.16 (4.85)

ΔH_f (kcal/mol (kJ/mol)): -30.73 (-128.6)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

λ: (est.) 0.21 Btu/hr-ft-°C (0.363 W/m-K) at 294 K

CTE:

α = (est.) 31 μin./in.-°F at -65 to -10°F (56 μm/m-K at 219-249 K)

α = (est.) 46 μin./in.-°F at 10-165°F (83 μm/m-K at 261-347 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): -18 (245)

C_p (cal/g-°C (kJ/kg-K)):

Est.: 0.31 (1.26)

Thermal stability (cm³ of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.01-0.04

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.32 (ρ= 1.87)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.87)

Meas.: —

Calc.: 310

E_{cyl} ((mm/μsec)²/2 (MJ/kg)): (ρ= 1.876)

6 mm: 1.105

19 mm: 1.360

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.59	—
2.5 kg:		

Susan test: Threshold velocity ~170 ft/sec (~53 m/s); is moderately difficult to ignite and has very low probability of buildup to violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (ρ= 1.867)

LANL-SSGT: 45-65 (1.1-1.7)

10. ELECTRICAL PROPERTIES:

ε: —

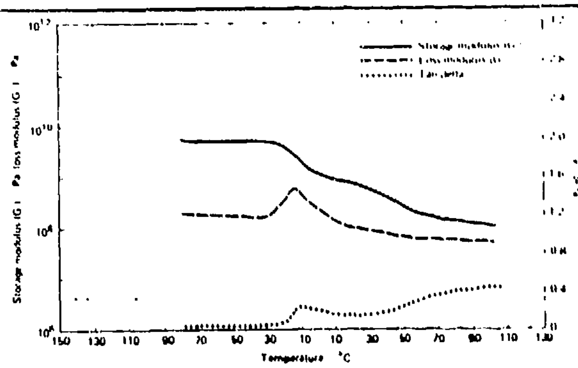
11. TOXICITY

—

LX-11

7. MECHANICAL PROPERTIES

Initial modulus



Complex shear moduli

Creep

Failure envelope

NOTES

EXPLOSIVE: LX-14-0	DESIGNATION: **LX-14**

2. STRUCTURE OR FORMULATION

	wt%
HMX	95.5
Estane 5702-F1	4.5

4. PHYSICAL PROPERTIES

Physical state: solid

Color: violet spots on white

At. comp.: $C_{1.52}H_{2.92}N_{2.59}O_{2.66}$

MW:

Density (g/cm^3): TMD: 1.849

Nominal: 1.83

m.p. (°C (K)): dec. >270 (>543)

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.58 (6.59)	1.43 (5.95)
Exp:		

ΔH_f (kcal/mol (kJ/mol)): +1.50 (+6.28)

Solubility (s-sol., sl-sl. sol., i-insol.): ___

6. THERMAL PROPERTIES

λ: 10.42×10^{-4} cal/cm-sec-°C (0.439 W/m-K) at 293 K

CTE: α = 27 μin./in.-°F <30°F
(48.5 μm/m-K <239 K)
α = 31 μin./in.-°F >30°F
(55.8 μm/m-K >239 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.02

1 g for 48 hr: 0.03

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.83 (ρ= 1.835)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.833)

Meas.: 370

Calc.: ——

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.835)

6 mm: 0.985

19 mm: 1.6143

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
2.5 kg:	0.53	0.51

Susan test: Threshold velocity ~48 m/s; is moderately easy to ignite. Accidental mechanical ignition would have moderately low probability of building to violent reaction or detonation.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	1.25 (0.38)	3
45 (0.79)	5.0 (1.52)	4

Gap test (mils (mm)): (ρ= 1.833)

LANL-SSGT: 60-80 (1.5-2.0)

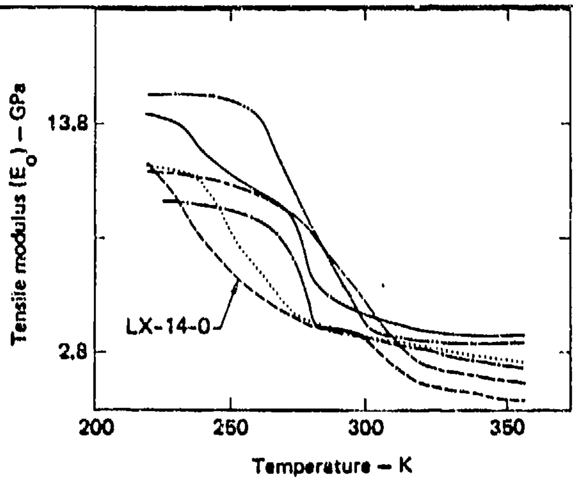
10. ELECTRICAL PROPERTIES:

ε:

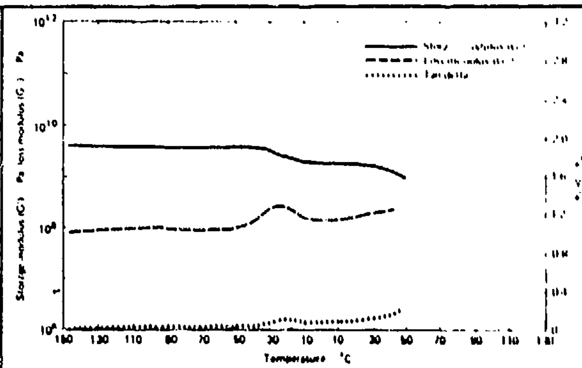
11. TOXICITY

1/82

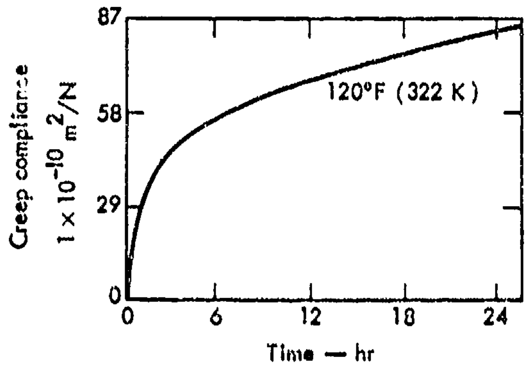
7. MECHANICAL PROPERTIES



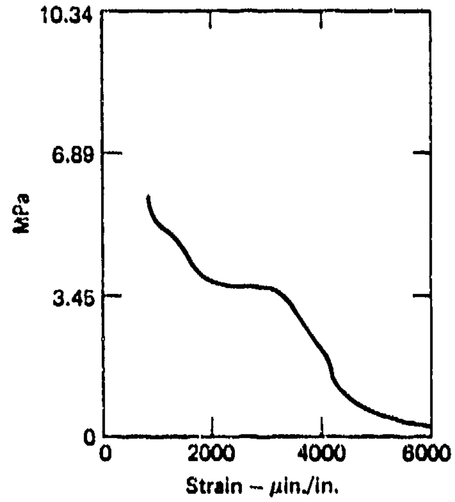
Initial modulus



Complex shear moduli

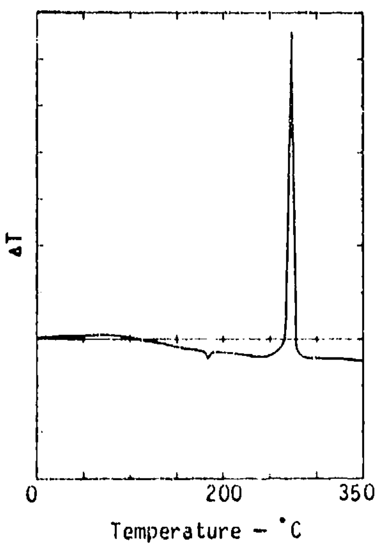


Creep

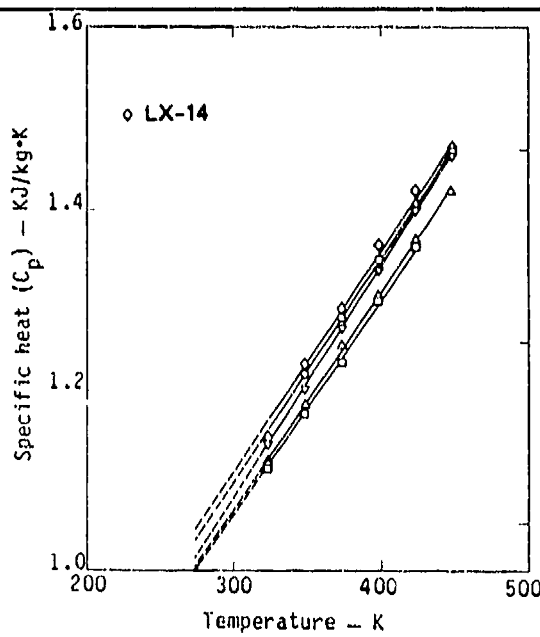


Failure envelope

NOTES



DTA curve



Specific heat vs T

EXPLOSIVE: LX-15	DESIGNATION: **LX-15**

2. STRUCTURE OR FORMULATION

	wt%
HNS-I	95
Kel-F 800	5

4. PHYSICAL PROPERTIES

Physical state: solid

Color: beige

At. comp.: $C_{3.05}H_{1.29}N_{1.27}O_{2.53}$ Cl:0.04 F:0.13

MW: 100

Density (g/cm^3): TMD: 1.752

Nominal:

m.p. (°C (K)): 313 (586)

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.53 (6.40)	1.34 (5.61)
Exp:		

ΔH_f (kcal/100g(kJ/100g)): -4.34 (-18.16)

Solubility (s-sol., sl-sl. sol., i-insol.):

6. THERMAL PROPERTIES

λ:

CTE:

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.069

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 6.84 (ρ= 1.584)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.58)

Meas.: --

Calc.: 188

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.58)

6 mm: 0.700

19 mm: 0.929

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
2.5 kg:	0.83	--

Susan test:

Skid test:

Impact angle (deg (rad)) Drop ht. (ft (m)) Event

(ρ =)

Gap test (mils (mm)): (ρ= --)

LANL-SSGT: 234 (5.94)

10. ELECTRICAL PROPERTIES:

ε:

11. TOXICITY

LX-15

7. MECHANICAL PROPERTIES

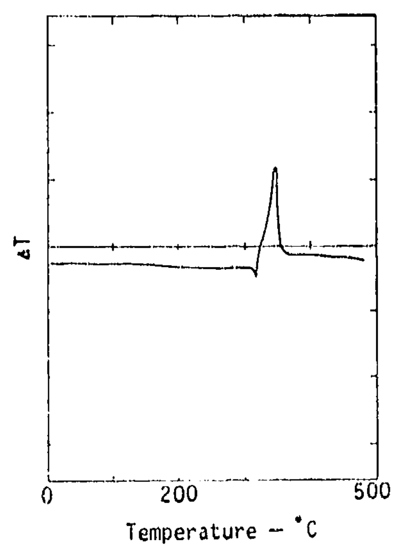
Sound velocity (km/s):	C_ℓ	C_s	C_b
(ρ = 1.58)	1.749	1.038	1.274

Initial modulus

Creep

Failure envelope

NOTES



DTA curve

EXPLOSIVE: LX-16

DESIGNATION: **LX-16**

2. STRUCTURE OR FORMULATION

	wt%
PETN	96
FPC 461	4

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_{1.61}H_{2.52}N_{1.22}O_{3.64}F_{0.05}$

MW:

Density (g/cm^3): TMD: 1.767

Nominal: 1.59-1.60

m.p. (°C (K)):

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.59 (6.65)	1.46 (6.11)
Exp:		

ΔH_f (kcal/mol (kJ/mol)): -42.71 (-178.7)

Solubility (s-sol., sl-sl. sol., i-insol.):

6. THERMAL PROPERTIES

λ:

CTE:

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: 0.38

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): (ρ=)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.:

Calc.:

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm:

19 mm:

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.18	

Susan test:

Skid test:

Impact angle (deg (rad)) Drop ht. (ft (m)) Event

Gap test (mils (mm)): (ρ=)

10. ELECTRICAL PROPERTIES:

ε:

11. TOXICITY

Moderate

3/81

LX-16

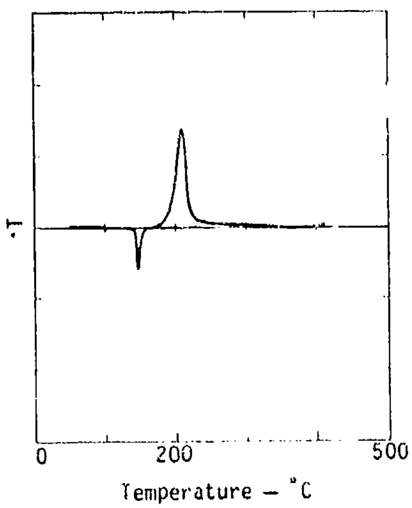
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES



DTA curve

EXPLOSIVE: LX-17-0

DESIGNATION: **LX-17**

2. STRUCTURE OR FORMULATION

	wt%
TATB	92.5
Kel-F 800	7.5

4. PHYSICAL PROPERTIES

Physical state: solid

Color: yellow

At. comp.: $C_{2.29}H_{2.18}N_{2.15}O_{2.15}$ Cℓ:0.054 F:0.2

MW: --

Density (g/cm^3): TMD: 1.944

Nominal: 1.89-1.94

m.p. (°C (K)):

b.p. (°C (K)):

v.p. (mm Hg (Pa)): 1.1×10^{-6} at 150°C (1.46×10^{-4} at 423 K)

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.31 (5.48)	1.02 (4.27)
Exp:	--	--

ΔH_f (kcal/mol (kj/mol)): -24.04 (-100.6)

Solubility (s-sol., sl-sl. sol., i-insol.):

6. THERMAL PROPERTIES

λ: 19.1×10^{-4} cal/sec-cm-°C at (0.799 W/m-K) at 293 K

CTE: α = 40.4 μm/m-K at 219-288 K
α = 60.2 μm/m-K at 288-347 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):
Exp. 0.27 (1.13)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: <0.02

1 g for 48 hr: ≤0.02

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.63 (ρ= 1.908)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.900)

Meas.: 300

Calc.:

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ= 1.908)

6 mm: 0.87

19 mm: 1.07

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
2.5 kg:	>1.77	--

Susan test: Behaves like a mock HE to threshold velocity of ~1000 m/s.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
no reaction		

Gap test (mils (mm)): PX-GT
(1.35) (ρ= 1.902) pressed
(2.29) (ρ = 1.899) machined

10. ELECTRICAL PROPERTIES:

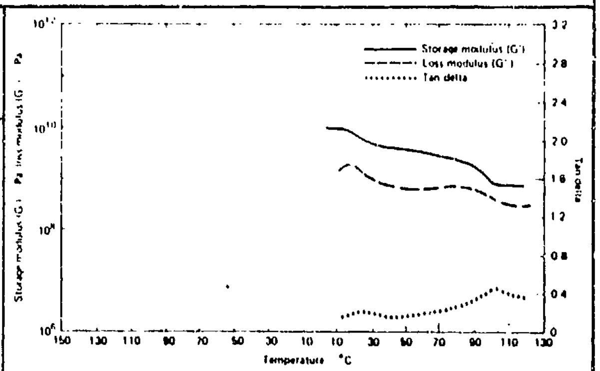
ε:

11. TOXICITY

LX-17

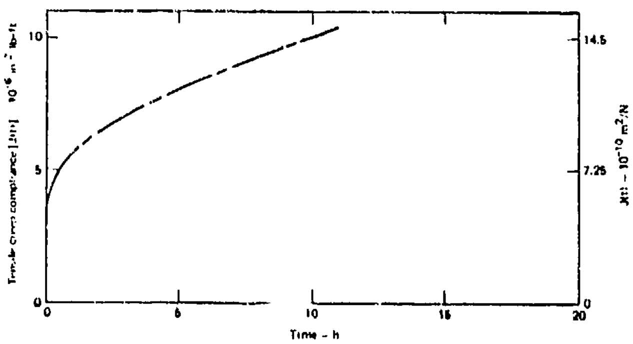
7. MECHANICAL PROPERTIES

Sound velocity (km/s):	C_ℓ	C_s	C_b
(ρ = 1.899)	2.815	1.366	2.24



Complex shear moduli

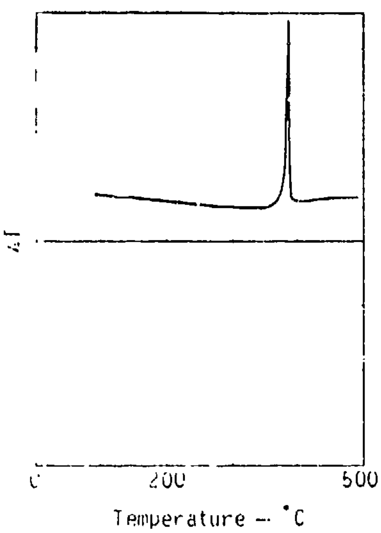
Initial modulus



Creep

Failure envelope

NOTES



DTA curve

1/82

EXPLOSIVE: MEN-II

DESIGNATION: **MEN-II**

2. STRUCTURE OR FORMULATION

	wt%
NM	72.2
Methanol	23.4
Ethylene diamine	4.4

4. PHYSICAL PROPERTIES

Physical state: liquid

Color: clear

At. comp.: $C_{2.06}H_{7.06}N_{1.33}O_{3.10}$

MW:

Density (g/cm^3): TMD: 1.017

Nominal:

m.p. (°C (K)): 313 (586)

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.38 (5.77)	1.05 (4.39)
Exp:		

ΔH_f (kcal/mol (kJ/mol)): -74.3 (-310.7)

Solubility (s-sol., sl-sl. sol., i-insol.):

6. THERMAL PROPERTIES

λ:

CTE:

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr:

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 5.49 (ρ= 1.02)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.017)

Meas.: --

Calc.: 113

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ=)

6 mm:

19 mm:

9. SENSITIVITY

H_{50} (m): 12 tool 12B tool

Susan test:

Skid test:

Impact angle (deg (rad)) Drop ht. (ft (m)) Event

Gap test (mils (mm)): (ρ=)

10. ELECTRICAL PROPERTIES:

ε:

11. TOXICITY

3/81

MEN-II

7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

EXPLOSIVE: MINOL-2

DESIGNATION: **Minol-2**

2. STRUCTURE OR FORMULATION

	wt%
AN	40
TNT	40
Al	20

4. PHYSICAL PROPERTIES

Physical state: solid

Color: gray

At. comp.: $C_{1.23}H_{2.88}N_{1.53}O_{2.56}Al_{0.74}$

MW: 100

Density (g/cm^3): TMD:

Nominal: 1.70

m.p. (°C (K)):

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	2.01 (8.41)	1.86 (7.78)
Exp:		

ΔH_f (kcal/100g (kJ/100g)): -46.43 (-194.3)

Solubility (s-sol., sl-sl. sol., i-insol.):

6. THERMAL PROPERTIES

λ: 16.5×10^{-4} cal/cm-sec-°C (0.690 W/m-K)

CTE:

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Exp. 0.30 at -5°C (1.25 at 268 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.105

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 5.82 (ρ= 1.68)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.:

Calc.:

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm:

19 mm:

9. SENSITIVITY

H_{50} (m): 12 tool 12B tool

Susan test:

Skid test:

Impact angle (deg (rad)) Drop ht. (ft (m)) Event

Gap test (mils (mm)): (ρ=)

10. ELECTRICAL PROPERTIES:

ε:

11. TOXICITY

Minol-2

7. MECHANICAL PROPERTIES

Initial modulus

Creep

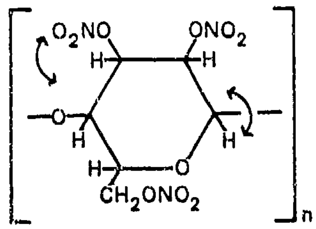
Failure envelope

NOTES

EXPLOSIVE: NITROCELLULOSE

DESIGNATION: **NC**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid — 14.14%N $[C_6H_7N_3O_{11}]_n$

Color: white

	12%N	13.35%N	14.14%N
At. comp.:	$[C_6H_{7.74}N_{2.26}O_{9.52}]_n$	$[C_6H_{7.29}N_{2.71}O_{10.41}]_n$	
MW:	$(263.9)_n$	$(283.9)_n$	(297.1)
Density (g/cm^3): TMD:	1.653	1.656	1.659
Nominal:	1.50		

m.p. (°C (K)): dec. >135 (408)
b.p. (°C (K)): —
v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
12% N Calc:	1.16 (4.85)	1.02 (4.27)
13.35% N Calc:	1.16 (4.85)	1.02 (4.27)

ΔH_f (kcal/mol (kJ/mol)): 12% N: -174 (-727)
13.35% N: -163 (-682)
14.14%N: -156 (-653)

Solubility (s-sol., sl-sl. sol., i-insol.):
s--acetone, ethyl acetate
sl--ethanol
i--carbon tetrachloride, chloroform, ethyl ether, water

6. THERMAL PROPERTIES

λ: 5.5×10^{-4} cal/cm-sec-°C (0.230 W/m-K) :12% N

CTE: α = 80-120 μm/m-K at 219-239 K 12% N

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Exp. 0.268 at 25°C (1.12 at 298 K) :12% N
Exp. 0.247 at 25°C (1.033 at 298 K) :13.35% N

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 1.0-1.2

1 g for 48 hr: 5.0

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): (ρ= 1.20)
13.35% N: 7.30

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.58)

Meas.: —

Calc.: 200 (12% N)
210 (13.35% N) (ρ = 1.58)

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	—	—
12% N: 2.5 kg:	0.50	0.57

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

None

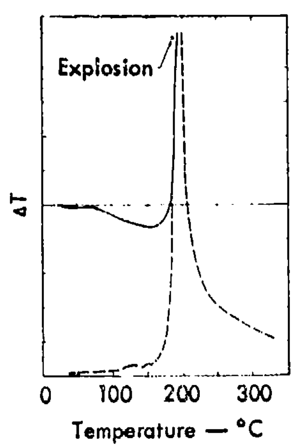
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

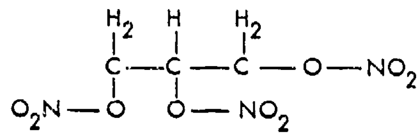


DTA (—) and pyrolysis (--) curves

EXPLOSIVE: 1,2,3-PROPANETRIOL TRINITRATE

DESIGNATION: **NG**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: liquid

Color: clear

At. comp.: $C_3H_5N_3O_9$

MW: 227.1

Density (g/cm^3): TMD: 1.596

Nominal: —

m.p. (°C (K)): 13.2 (286)
b.p. (°C (K)): —
v.p. (mm Hg (Pa)): 0.0015 at 20°C (0.2 at 293 K)

Crystal data: —

R: —

n: 1.4732 at 20°C (293 K)

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.59 (6.65)	1.48 (6.19)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): -88.6 (-371)

Solubility (s-sol., sl-sl. sol., i-insol.):
s — acetone, benzene, chloroform, ethanol, ethyl acetate, ethyl ether, nitric acid, sulfuric acid, pyridine
sl — carbon disulfide, carbon tetrachloride, water

6. THERMAL PROPERTIES

λ: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Exp. 0.356 at 35-200°C (1.49 at 308-473 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.70 (ρ= 1.60)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.59)

Meas.: 253

Calc.: 251

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	—	—
2.5 kg:	0.20	

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

High

NG

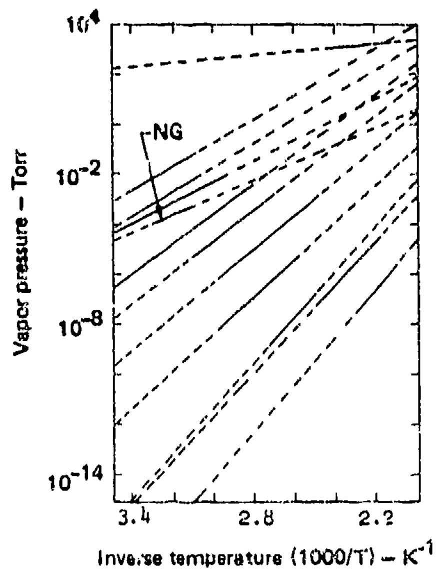
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

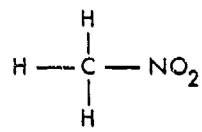


Vapor pressure vs 1/T

EXPLOSIVE: NITROMETHANE

DESIGNATION: **NM**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: liquid

Color: clear

At. comp.: $C_1H_3N_1O_2$

MW: 61.0

Density (g/cm^3): TMD: 1.13 at 293 K

Nominal: —

m.p. (°C (K)): -29 (244)

b.p. (°C (K)): 101 (374)

v.p. (mm Hg (Pa)): 37 at 25°C (4933 at 298 K)

Crystal data: ($P2_12_12_1$) at -268.8°C

a = 5.18
b = 6.24
c = 8.52

R: —

n: 1.641 at 20.4°C and 8.65 GPa

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.62 (6.78)	1.36 (5.69)
Exp:	1.23 (5.15)	1.06 (4.44)

ΔH_f (kcal/mol (kJ/mol)): -27 (-113)

Solubility (s-sol., sl-sl. sol., i-insol.):

s—DMFA, DMSO, ethanol, ethyl ether, water

6. THERMAL PROPERTIES

λ: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 6.35 (ρ= 1.13)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.135)

Meas.: 125

Calc.: 144

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.14)

6 mm: 0.560
19 mm: 0.745 } at 284-288 K

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	—	—
2.5 kg:	>3.20	--

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (modified) (ρ= —)

LANL-SSGT: 7-17 (0.18-0.43)
LANL-SSGT: 2-8 (0.05-0.20)
SRI-GT: (5.1-10.2)

10. ELECTRICAL PROPERTIES:

ϵ : —

11. TOXICITY

Moderate

NM

7. MECHANICAL PROPERTIES

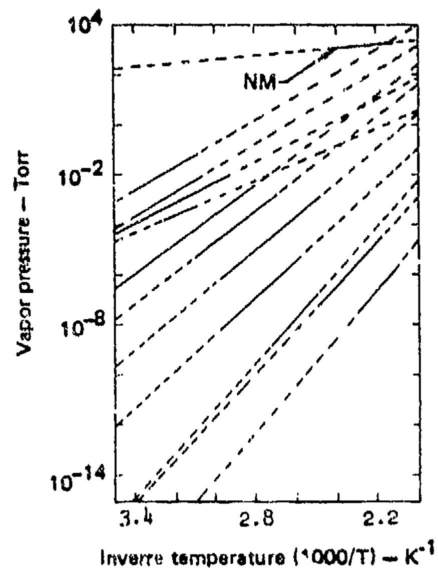
Sound velocity (km/s):	C_ℓ	C_s	C_b
(ρ = 1.14)	--	--	1.33

Initial modulus

Creep

Failure envelope

NOTES

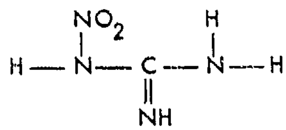


Vapor pressure vs 1/T

EXPLOSIVE: NITROGUANIDINE

DESIGNATION: **NQ**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_1H_4N_4O_2$

MW: 104.1

Density (g/cm^3): TMD: 1.775

Nominal: 1.55-1.75

m.p. (°C (K)): 257(530)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: orthorhombic (Fdd2)

a = 17.62
b = 24.85
c = 3.59

R: 25.2 (calc.), 22.2 (obs.)

n: see Table 4-3.

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.06 (4.44)	0.88 (3.68)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): -22.1 (-92.5)

Solubility (s-sol., sl-sl. sol., i-insol.):
s--DMFA, sulfuric acid
sl--ethanol, nitric acid
i--acetone, benzene, carbon disulfide, carbon tetrachloride, chloroform, ethyl acetate, ethyl ether, water

6. THERMAL PROPERTIES

λ: 10.14×10^{-4} cal/cm-sec-°C (0.424 W/m-K) at 314 K

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Exp. 6 + 0.08T at 200-460°C

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.02-0.05

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/µsec (km/s)): 7.65 (ρ = 1.55)

P_{CJ} (kbar (10^{-1} GPa)): (ρ =)

Meas.: —

Calc.: —

E_{cyl} ((mm/µsec)^2/2 (MJ/kg)): (ρ =)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	>1.77	—
2.5 kg:	>3.20	>3.20

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (ρ =)

NSWC-SSGT:	(2.72)	(ρ = 1.273)
LANL-SSGT:	NO GO	(ρ = 1.575)
LANL-LSGT:	NO GO	(ρ = 1.715)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

High

NQ

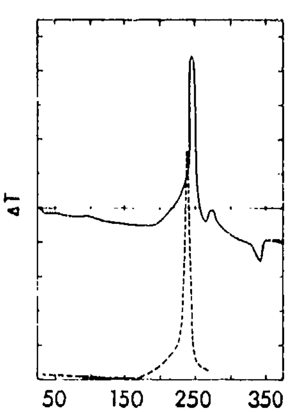
7. MECHANICAL PROPERTIES

Initial modulus

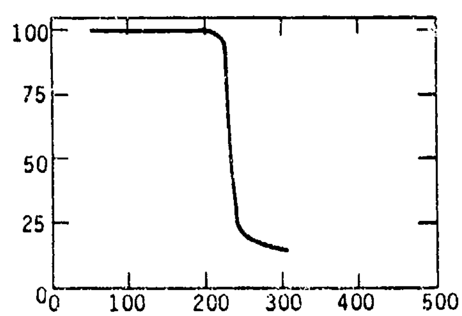
Creep

Failure envelope

NOTES



DT^1 (—) and pyrolysis (--) curves



TGA curve

EXPLOSIVE: OCTOL 75/25

DESIGNATION: **Octol**

2. STRUCTURE OR FORMULATION

	wt%
HMX	75
TNT	25

4. PHYSICAL PROPERTIES

Physical state: solid

Color: buff

At. comp.: $C_{1.78}H_{2.58}N_{2.36}O_{2.69}$

MW: 100

Density (g/cm^3): TMD: 1.843

Nominal: 1.80-1.82

m.p. (°C (K)): 79-80 (352-353)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): 0.1 at 100°C (13.33 at 373 K)

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.57 (6.57)	1.43 (5.98)
Exp:	—	—

ΔH_f (kcal/100g (kJ/100g)): +2.78 (+11.63)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

λ: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):

Est.: 0.27 (1.13)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.028

1 g for 48 hr: 0.18

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.48 (ρ= 1.81)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.821)

Meas.: 342

Calc.: —

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ= 1.813)

6 mm: 1.215

19 mm: 1.535

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.41	—
2.5 kg:	0.35-0.52	0.49-2.70

Susan test: Threshold velocity ~180 ft/sec (~55 m/s); is rather difficult to ignite accidentally, but capable of large reaction once ignited.

Skid test:

	Impact angle (deg (rad))	Drop ht. (ft (m))	Event
75/25:	14 (0.24)	3.5 (1.07)	3

Gap test (mils (mm)):

75/25:	NSWC-SSGT:	(4.88)	(ρ = 1.829)
75/25:	LANL-SSGT:	22-28 (0.56-0.71)	(ρ = 1.810)
75/25:	LANL-LSGT:	1.947 (49.5)	(ρ = 1.822)

10. ELECTRICAL PROPERTIES:

ε: 3.20 (ρ = 1.81)

11. TOXICITY

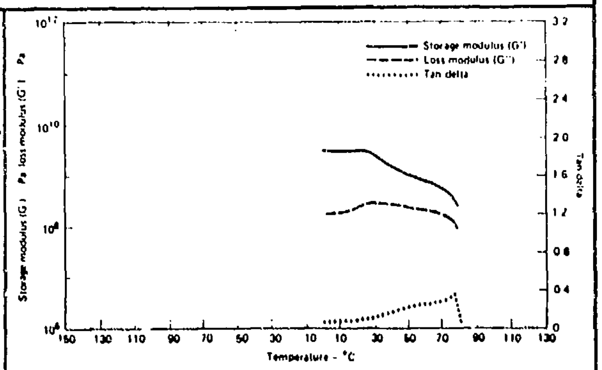
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1/85

Octol

7. MECHANICAL PROPERTIES

Sound velocity (km/s):	C_ℓ	C_s	C_b
(ρ = 1.80)	3.14	1.66	2.49



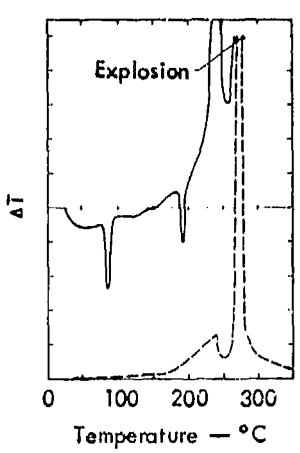
Complex shear moduli

Initial modulus

Creep

Failure envelope

NOTES



DTA (—) and pyrolysis (--) curves

EXPLOSIVE: PBX-9007

DESIGNATION: **PBX-9007**

2. STRUCTURE OR FORMULATION

	wt%
RDX	90
Polystyrene	9.1
DOP	0.5
Rosin	0.4

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white or mottled gray

At. comp.: $C_{1.97}H_{3.22}N_{2.43}O_{2.44}$

MW:

Density (g/cm^3): TMD: 1.697

Nominal: 1.66

m.p. (°C (K)): dec. >200 (>473)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.56 (6.53)	1.39 (5.82)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): +7.13 (+29.8)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

λ: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.28 (1.17)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.03-0.07

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.09 (ρ= 1.64)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.60)

Meas.: 265

Calc.: —

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.35	0.28
2.5 kg:	0.39	--

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):

LANL-SSGT: (2.01) (ρ = 1.638)

LANL-LSGT: (52.91) (ρ = 1.646)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

—

PBX-9007

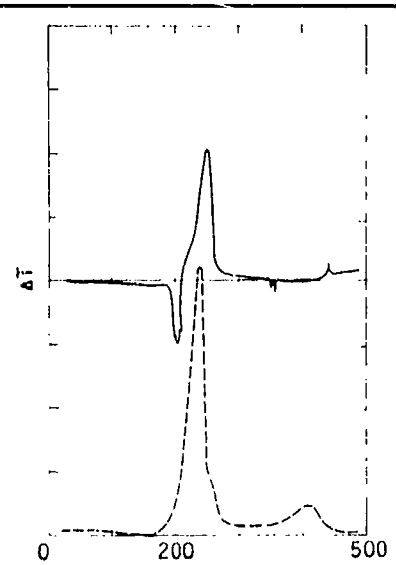
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES



DTA (—) and pyrolysis (--) curves

EXPLOSIVE: PBX-9010

DESIGNATION: **PBX-9010**

2. STRUCTURE OR FORMULATION

	wt%
RDX	90
Kel-F	10

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_{1.39}H_{2.43}N_{2.43}O_{2.43}Cl_{0.09}F_{0.26}$

MW:

Density (g/cm^3): TMD: 1.822

Nominal: 1.79

m.p. (°C (K)): dec. >200 (>473)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.47 (6.15)	1.36 (5.69)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): -7.87 (-32.9)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

λ: 5.14×10^{-4} cal/cm-sec-°C (0.215 W/m-K) at 322 K

CTE: α = 66 μm/m-K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.27 (1.13)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.02-0.04

1 g for 48 hr: 0.2-0.3

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.37 (ρ= 1.78)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.783)

Meas.: 328 ± 5

Calc.: —

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.788)

6 mm: 1.160

19 mm: 1.470

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.30	0.45
2.5 kg:	0.31-0.41	0.31-0.92

Susan test: Threshold velocity ~110 ft/sec (~34 m/s); has high probability of rapid buildup to violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	1.25 (0.38)	6
45 (0.79)	3.5 (1.07)	6

Gap test (mils (mm)):

LANL-SSGT:	75-95 (1.9-2.4)	(ρ = 1.783)
LANL-LSGT:	2.090 (53.09)	(ρ = 1.786)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

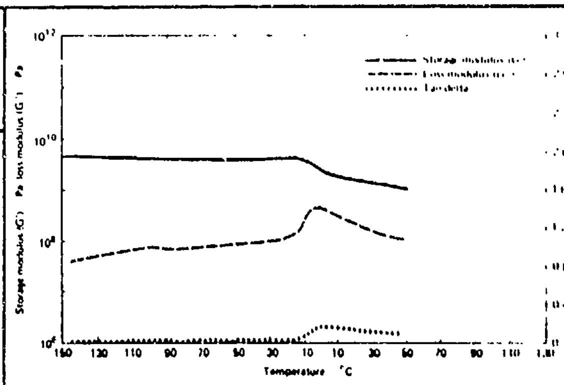
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PBX-9010

7. MECHANICAL PROPERTIES

Sound velocity (km/s):	C_ℓ	C_s	C_b
(ρ = 1.78)	2.72	1.47	2.13

Initial modulus



Complex shear moduli

Creep

Failure envelope

NOTES



DTA (—) and pyrolysis (--) curves

EXPLOSIVE: PBX-9011

DESIGNATION: **PBX-9011**

2. STRUCTURE OR FORMULATION

	wt%
HMX	90
Estane	10

4. PHYSICAL PROPERTIES

Physical state: solid

Color: off-white

At. comp.: $C_{1.73}H_{3.18}N_{2.45}O_{2.61}$

MW:

Density (g/cm^3): TMD: 1.795

Nominal: 1.77

m.p. (°C (K)): dec. >250 (>523)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.53 (6.40)	1.36 (5.69)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): -4.05 (-17)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

λ: 0.25 Btu/hr-ft- F (0.432 W/m-K) at 294 K

CTE: α = 28.7 μin./in.-°F at -65 to -40°F
(51.7 μm/m-K at 219-233 K)
α = 37.3 μin./in.-°F at -30 to 165°F
(67.1 μm/m-K at 243-347 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): -35 (236)

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.27 (1.13)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.024

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.50 (ρ= 1.77)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.767)

Meas.: 324 ± 5

Calc.: —

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ= 1.777)

6 mm: 1.120

19 mm: 1.415

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.44	0.98
2.5 kg:	0.45-0.89	0.53-0.93

Susan test: Threshold velocity ~165 ft/sec (~50 m/s); is moderately difficult to ignite and has very low probability of buildup to a violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	20.0 (6.10)	1
45 (0.79)	20.0 (6.10)	0

Gap test (mils (mm)):

LANL-SSGT:	55-70 (1.4-1.8)	(ρ = 1.783)
LANL-LSGT:	(51.97)	(ρ = 1.761)

10. ELECTRICAL PROPERTIES:

ε: —

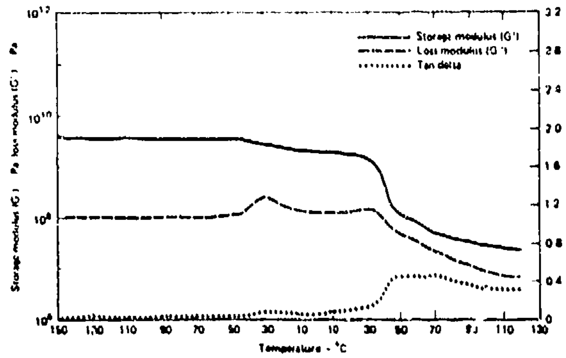
11. TOXICITY

—

PBX-9011

7. MECHANICAL PROPERTIES

Sound velocity (km/s):	C_ℓ	C_s	C_b
(ρ = 1.790)	2.89	1.38	2.41



Complex shear moduli

Initial modulus

Creep

Failure envelope

NOTES

EXPLOSIVE: PBX-9205

DESIGNATION: **PBX-9205**

2. STRUCTURE OR FORMULATION

	wt%
RDX	92
Polystyrene	6
DOP	2

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_{1.83}H_{3.14}N_{2.49}O_{2.51}$

MW:

Density (g/cm^3): TMD: 1.72

Nominal: 1.68

m.p. (°C (K)): dec. >200 (>473)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.46 (6.11)	1.41 (5.90)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): +5.81 (+24.30)

Solubility (s-sol., sl-sl, sol., i-insol.): —

6. THERMAL PROPERTIES

λ: —

CTE: α = 54 μm/m-K at 200 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.28 (1.17)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.025

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.17 (ρ= 1.67)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.69)

Meas.: —

Calc.: 288

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.42	0.36
2.5 kg:	0.44–0.60	0.48–0.56

Susan test: Threshold velocity ~ 120 ft/sec (~ 37 m/s); has moderate probability of buildup to a violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	1.25 (0.38)	2
45 (0.79)	2.5 (0.76)	4

Gap test (mils (mm)):

LANL-SSGT:	25–35 (0.64–0.89)	(ρ = 1.682)
LANL-LSGT:	(50.83)	(ρ = 1.682)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

—

PBX-9205

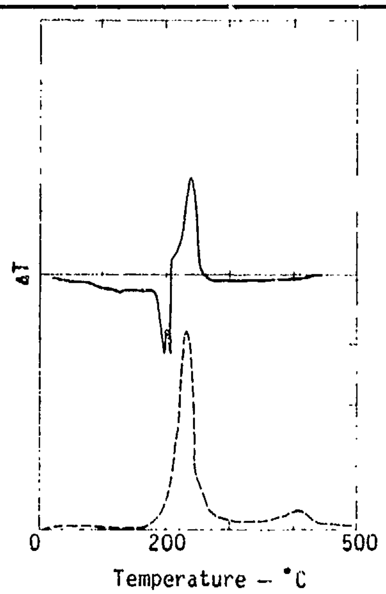
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES



DTA (—) and pyrolysis (--) curves

EXPLOSIVE: PBX-9404-03

DESIGNATION: **PBX-9404**

2. STRUCTURE OR FORMULATION

	wt%
HMX	94
NC	3
CEF	3

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white or blue

At. comp.: $C_{1.40}H_{2.75}N_{2.57}O_{2.69}Cl_{0.03}P_{0.01}$

MW:

Density (g/cm^3): TMD: 1.865

Nominal: 1.83-1.84

m.p. (°C (K)): dec. >250 (>523)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.56 (6.53)	1.42 (5.94)
Exp:	1.38 (5.77)	1.28 (5.36)

ΔH_f (kcal/mol (kJ/mol)): +0.08 (+0.331)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

λ: 0.25 Btu/hr-ft-°F (0.432 W/m-K) at 294 K

CTE: α = 28.1 μin./in.-°F at -65 to -30°F
(50.6 μm/m-K at 219-239 K)
α = 32.2 μin./in.-°F at -10 to 165°F
(58.0 μm/m-K at 250-347 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): -29 (239)

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.27 (1.13)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.36-0.40

1 g for 48 hr: 3.2-4.9

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.80 (ρ= 1.84)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.840)

Meas.: 375

Calc.: 354

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.843)

6 mm: 1.295

19 mm: 1.620

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.34	0.35
2.5 kg:	0.33-0.48	0.35-0.57

Susan test: Threshold velocity 105 ft/sec (32 m/s); has very large probability of buildup to violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	0.88 (0.27)	6
45 (0.79)	3.5 (1.07)	6

Gap test (mils (mm)):

LANL-SSGT:	85-105	(2.2-2.7)	(ρ = 1.850)
LANL-LSGT:	2.268	(57.61)	(ρ = 1.841)
PX-GT:		(27.3)	(ρ = --)

10. ELECTRICAL PROPERTIES:

ε: 3.52 (ρ = 1.84)

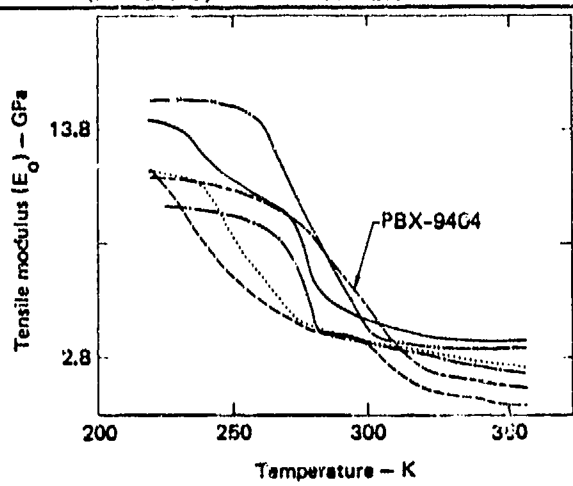
11. TOXICITY

—

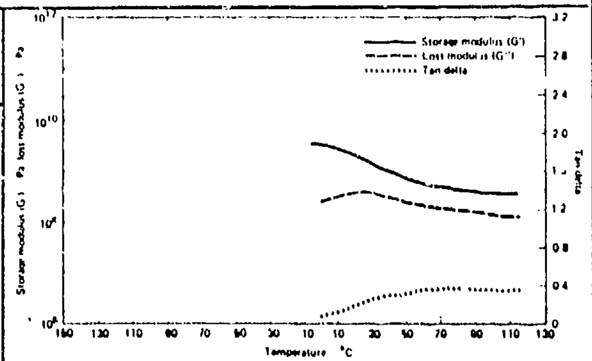
PBX-9404

7. MECHANICAL PROPERTIES

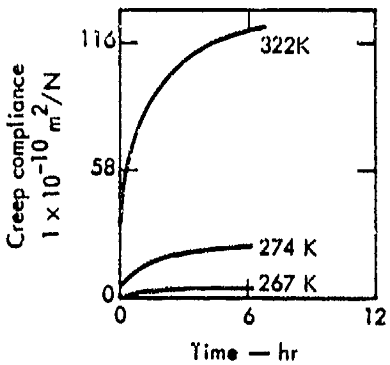
Sound velocity (km/s):	C_ℓ	C_s	C_b
(ρ = 1.840)	2.90	1.57	2.26



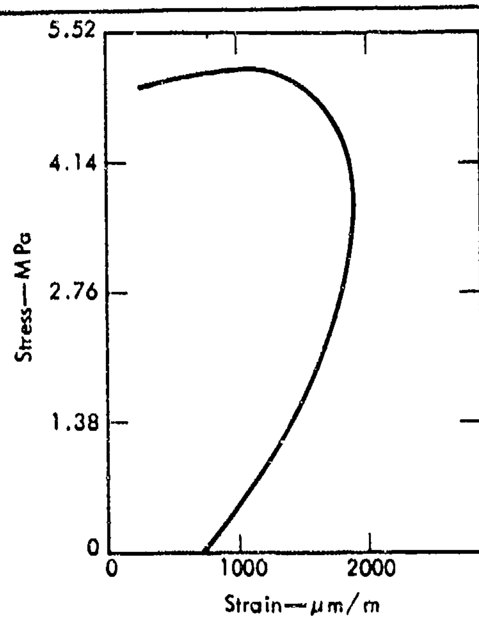
Initial modulus



Complex shear moduli

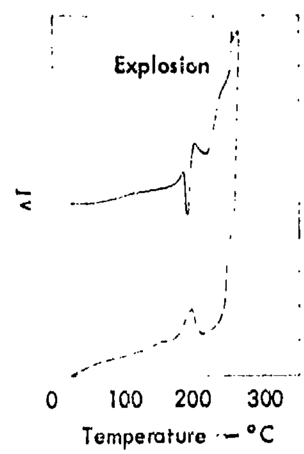


Creep



Failure envelope

NOTES



DTA (—) and pyrolysis (--) curves

EXPLOSIVE: PBX-9407

DESIGNATION: **PBX-9407**

2. STRUCTURE OR FORMULATION

	wt%
RDX	94
Exon 461	6

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white or black

At. comp.: $C_{1.41}H_{2.66}N_{2.54}O_{2.54}Cl_{0.07}F_{0.09}$

MW:

Density (g/cm^3): TMD: 1.81

Nominal: 1.60-1.62

m.p. (°C (K)): dec. >200 (>473)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.60 (6.69)	1.46 (6.11)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): +0.81 (+3.39)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

λ: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):

Est.: 0.27 (1.13)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.06

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.91 (ρ= 1.60)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.60)

Meas.: 287

Calc.: 300

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.33	0.30
2.5 kg:	0.46	0.46

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):

NSWC-SSGT:		(6.55)	(ρ = 1.755)
LANL-SSGT:	90-120	(2.3-3.1)	(ρ = 1.770)
LANL-LSGT:	2.155	(54.74)	(ρ = 1.772)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

—

PBX-9407

7. MECHANICAL PROPERTIES

Sound velocity (km/s):

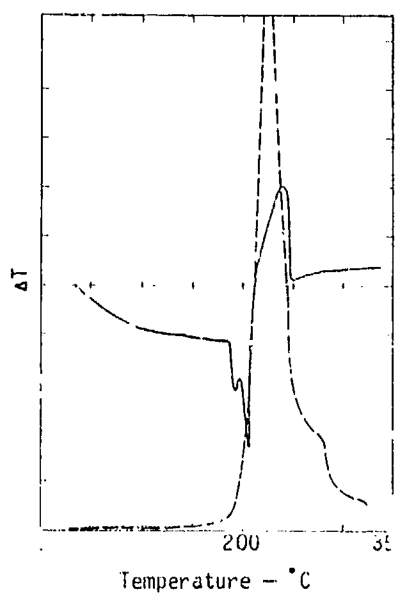
	c_ℓ	c_s	c_b
(ρ = 1.78)	3.04	1.70	2.32

Initial modulus

Creep

Failure envelope

NOTES



DTA (—) and pyrolysis (--) curves

EXPLOSIVE: PBX-9501

DESIGNATION: **PBX-9501**

2. STRUCTURE OR FORMULATION

	wt%
HMX	95
Estane	2.5
BDNPA-F	2.5

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_{1.47}H_{2.86}N_{2.60}O_{2.69}$

MW:

Density (g/cm^3): TMD: 1.855

Nominal: 1.84

m.p. (°C (K)): dec. >240 (>515)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.59 (6.65)	1.44 (6.03)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): +2.3 (+9.5)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

λ: 10.84 cal/cm-sec-°C (0.454 W/m-K) at 328 K

CTE:
α = 30.6 μin./in.-°F at -80 to 160°F
α = (55.1 μm/m-K at 211-344 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.27 (1.13)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr:

1 g for 48 hr: 0.8

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.83 (ρ= 1.84)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.: —

Calc.:

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ= 1.834)

6 mm: 1.177

19 mm: 1.577

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.44	0.80
2.5 kg:	0.42-0.57	0.41-0.84

Susan test: Threshold velocity ~ 200 ft/sec (~61 m/s); once this velocity is exceeded, reactions become violent over a narrow range. Small reactions do not automatically grow to large ones.

Skid test:

	Impact angle (deg (rad))	Drop ht. (ft (m))	Event
	14 (0.24)	10 (3.05)	3
	45 (0.79)	10 (3.05)	0
as pressed:	14 (0.24)	1.75 (0.53)	3
	45 (0.79)	7.1 (2.16)	3

Gap test (mils (mm)):

LANL-SSGT: 50-70 (1.3-1.8) (ρ = 1.843)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

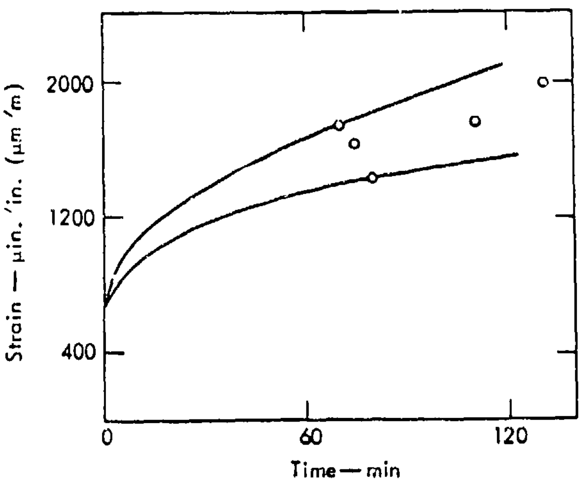
—

PBX-9501

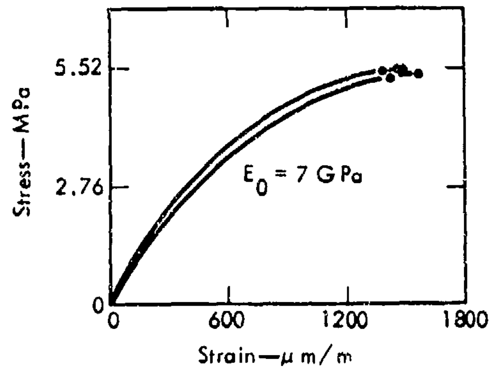
7. MECHANICAL PROPERTIES

Sound velocity (km/s)	c_ℓ	c_s	c_b
(ρ = 1.82)	2.97	1.39	2.50

Initial modulus

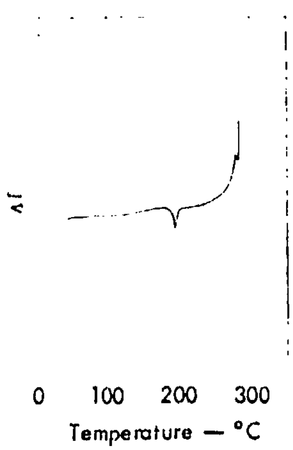


Creep



Failure envelope

NOTES



DTA curve

EXPLOSIVE: PBX-9502

DESIGNATION: **PBX-9502**

2. STRUCTURE OR FORMULATION

	wt%
TATB	95
Kel-F 800	5

4. PHYSICAL PROPERTIES

Physical state: solid

Color: yellow

At. comp.: $C_{2.30}H_{2.23}N_{2.21}O_{2.21}Cl_{0.038}F_{0.13}$

MW:

Density (g/cm^3): TMD: 1.942

Nominal: 1.90

m.p. (°C (K)): decomp. >400(>673)

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.15 (4.81)	1.05 (4.18)
Exp:		

ΔH_f (kcal/mol (kJ/mol)): -20.8 (-87)

Solubility (s-sol., sl-sl. sol., i-insol.):

6. THERMAL PROPERTIES

λ: 13.2×10^{-4} cal/cm-sec-°C (0.552 W/m-K) at 311 K

CTE: α ~ 44 μm/m-K at 200 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 for 22 hr:

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.71 (ρ= 1.90)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.:

Calc.:

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.889)

6 mm: 0.845

19 mm: 1.037

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
2.5 kg:	>3.20	>3.20

Susan test:

Skid test:

Impact angle (deg (rad)) Drop ht. (ft (m)) Event

Gap test (mils (mm)):

LANL-SSGT:	(4.44)	(ρ = 1.895)
LANL-LSGT:	(22.33)	(ρ = 1.895)
PX-GT:	(6.8)	(ρ = 1.895)

10. ELECTRICAL PROPERTIES:

ε:

11. TOXICITY

PBX-9502

7. MECHANICAL PROPERTIES

Sound velocity (km/s):	C_ℓ	C_s	C_b
(ρ = 1.88)	2.74	1.38	2.20

Initial modulus

Creep

Failure envelope

NOTES

EXPLOSIVE: PBX-9503	DESIGNATION: **PBX-9503**

2. STRUCTURE OR FORMULATION

	wt%
HMX	15
TATB	80
Kel-F 800	5

4. PHYSICAL PROPERTIES

Physical state: solid

Color: purple

At. comp.: $C_{2.16}H_{2.28}N_{2.26}O_{2.26}Cl_{0.038}$

MW:

Density (g/cm^3): TMD: 1.936

Nominal: 1.88

m.p. (°C (K)):
b.p. (°C (K)):
v.p. (mm Hg (Pa)):

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.22 (5.10)	1.11 (4.64)
Exp:		

ΔH_f (kcal/mol (kJ/mol)): -17.7 (-74)

Solubility (s-sol., sl-sl. sol., i-insol.):

6. THERMAL PROPERTIES

λ:

CTE:

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr:

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.72 (ρ= 1.90)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.:

Calc.:

E_{cyl}((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm:

19 mm:

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
2.5 kg:	--	1.74

Susan test:

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event

Gap test (mils (mm)): (ρ=)

LANL-LSGT: (42.8) (ρ = 1.88)

10. ELECTRICAL PROPERTIES:

ε:

11. TOXICITY

PBX-9503

7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES

EXPLOSIVE: PENTOLITE 50/50

DESIGNATION: **Pentolite**

2. STRUCTURE OR FORMULATION

	wt%
PETN	50
TNT	50

4. PHYSICAL PROPERTIES

Physical state: solid

Color: yellow-white

At. comp.: $C_{2.33}H_{2.37}N_{1.29}O_{3.22}$

MW: 100

Density (g/cm^3): TMD: 1.71

Nominal: 1.67

m.p. (°C (K)): 76 (349)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): 0.1 at 100°C (13.33 at 373 K)

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.53 (6.40)	1.40 (5.86)
Exp:	1.23 (5.15)	1.16 (4.85)

ΔH_f (kcal/100g (kJ/100g)): -23.9 (-99.9)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

λ: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.26 (1.09)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: —

1 g for 48 hr: 3.0 at 100°C (373 K)

8. DETONATION PROPERTIES

D (mm/µsec (km/s)): 7.53 (ρ= 1.70)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.70)

Meas.: —

Calc.: 255

E_{cyl}((mm/µsec)^2/2 (MJ/kg)): (ρ= 1.696)

6 mm: 0.960

19 mm: 1.260

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	~0.35	—
2.5 kg:	--	--

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):

NSWC-SSGT: (10.03) (ρ = 1.671)

LANL-SSGT: (3.12) (hot pressed)(ρ = 1.676)

30-38 (0.76-0.97) (cast) (ρ = 1.700)

LANL-LSGT: 2.549 (64.74) (ρ = 1.702)

10, ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

—

Pentolite

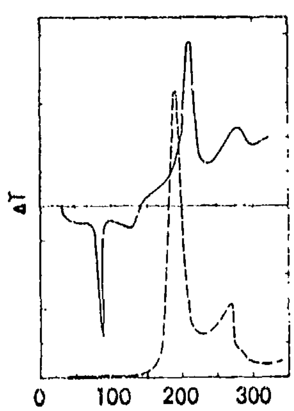
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

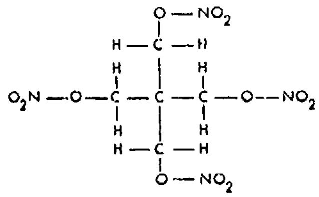
NOTES



DTA (—) and pyrolysis (--) curves

EXPLOSIVE: 2,2-BIS[(NITROXY)METHYL]-1,3-PROPANEDIOL, DINITRATE	DESIGNATION: **PETN**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_5H_8N_4O_{12}$

MW: 316.2

Density (g/cm^3): TMD: 1.78

Nominal: 1.76

m.p. (°C (K)): 140 (413)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)):

8×10^{-5} at 100°C (1.1×10^{-3} at 373 K)

Crystal data:

I: tetragonal ($P42_1/c$)	II: orthorhombic (Pcnb)
a = 9.38	a = 13.29
c = 6.70	b = 13.49
	c = 6.83

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.65 (6.90)	1.51 (6.32)
Exp:	1.49 (6.23)	1.37 (5.73)

ΔH_f (kcal/mol (kJ/mol)): -128.7 (-538.5)

Solubility (s-sol., sl-sl. sol., i-insol.):

s—acetone, DMFA, DMSO, ethyl acetate, pyridine
sl—benzene, ethyl ether
i—carbon disulfide, carbon tetrachloride, chloroform, ethanol, water

6. THERMAL PROPERTIES

λ: —

CTE: α = 46.1 μin./in.-°F (83.0 m/m-K)
α = 76.5 μm/m-K at 293 K
α = 89.9 μm/m-K at 363 K
β = 249.2 μm/m-K at 243-343 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): none

C_p (cal/g-°C (kJ/kg-K)):

Exp.: 0.26 at 20°C (1.088 at 293 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.10-0.14

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.26 (ρ = 1.76)

P_{CJ} (kbar (10^{-1} GPa)):

	ρ = 1.77	ρ = 1.67	ρ = 0.99
Meas.:	335	300	87
Calc.:	332	280	100

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ = 1.765)

6 mm: 1.255

19 mm: 1.575

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.11	—
2.5 kg:	0.13-0.16	0.14-0.20

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):

NSWC-SSGT:		(6.03)	(ρ = 1.775)
LANL-SSGT:		(5.21)	(ρ = 1.757)
LANL-LSGT:	2.732	(69.4)	(ρ = 0.81)

10. ELECTRICAL PROPERTIES:

ε: 2.447 (ρ = 1.4)
2.577 (ρ = 1.5) 2.897 (ρ = 1.7)
2.727 (ρ = 1.6) 2.95 (ρ = 1.75)

11. TOXICITY

High

1/85

PETN

7. MECHANICAL PROPERTIES

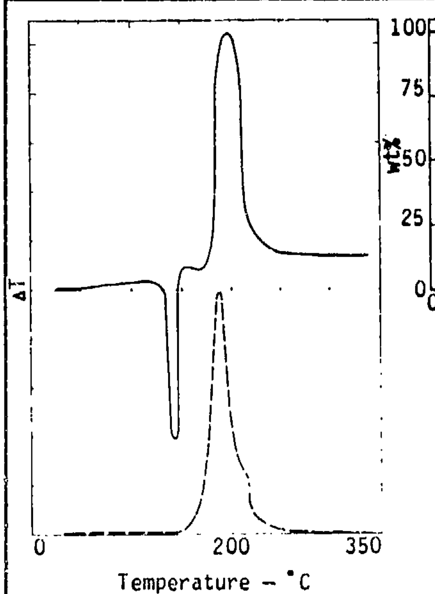
Sound velocity (km/s)	C_ℓ	C_s	C_b
(ρ = 1.77)	--	--	2.32

Initial modulus

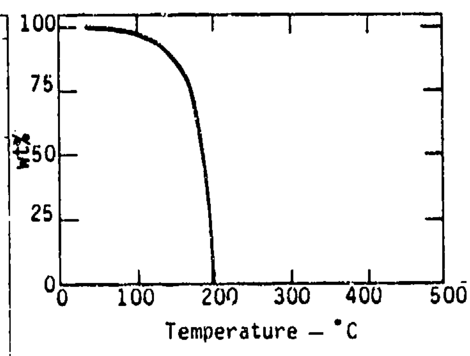
Creep

Failure envelope

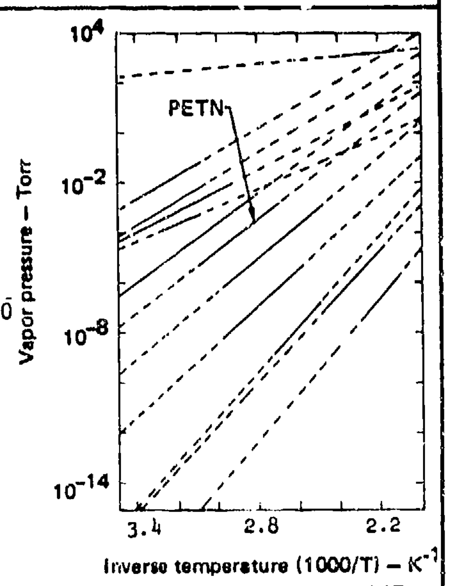
NOTES



DTA (—) and pyrolysis (--) curves



TGA curve

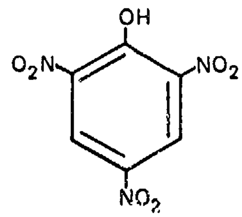


Vapor pressure vs 1/T

EXPLOSIVE: 2,4,6-TRINITROPHENOL

DESIGNATION: **Picric acid**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: yellow

At. comp.: $C_6H_3N_3O_7$

MW: 229.1

Density (g/cm^3): TMD: 1.76

Nominal: 1.60

m.p. (°C (K)): 122 (395)

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

Crystal data: orthorhombic ($C_{2}^{5}v$)

a = 9.25

b = 19.08

c = 9.68

R:

n: 1.620 at m.p. (122°C)

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:		
Exp:		

ΔH_f (kcal/mol (kJ/mol)): -51.3 (-214.5)

Solubility (s-sol., sl-sl. sol., i-insol.):

s--acetone, benzene, chloroform, ethanol, ethyl acetate

sl--carbon disulfide, ethyl ether, sulfuric acid, water

6. THERMAL PROPERTIES

λ: 2.4×10^{-4} cal/cm-sec-°C (0.100 Wm/-K)

CTE:

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Exp. 0.234 at 0°C (0.979 at 273 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr:

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.26 (ρ= 1.71)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

	ρ = 1.76	ρ = 1.00
Meas.:	--	--
Calc.:	265	88

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ =)

6 mm:

19 mm:

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
2.5 kg:	0.73	1.91

Susan test:

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event

Gap test (mils (mm)): (ρ=)

10. ELECTRICAL PROPERTIES:

ε: 3.59 (ρ = 1.764)

11. TOXICITY

Moderate

Picric acid

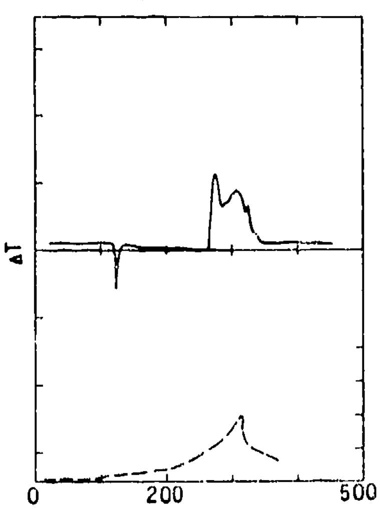
7. MECHANICAL PROPERTIES

Initial modulus

Creep

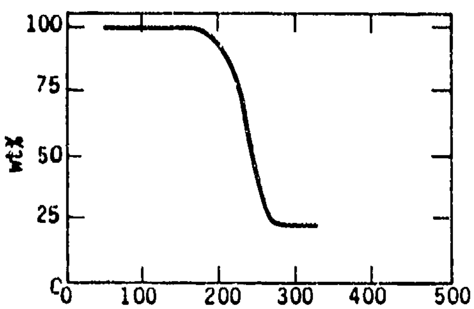
Failure envelope

NOTES



Temperature — °C

DTA (—) and pyrolysis (--) curves



Temperature — °C

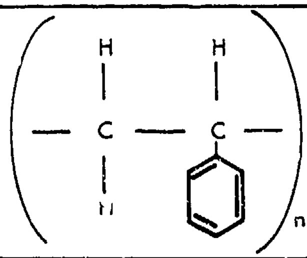
TGA curve

MATERIAL: POLYSTYRENE
(Binder)

DESIGNATION : **Polystyrene**

SUPPLIER :

2. STRUCTURAL FORMULATION



4. PHYSICAL PROPERTIES

Physical state : solid

Color : clear

At. comp. : $(C_8H_8)_n$

MW : $(104.2)_n$

Density (g/cm^3) : TMD : 1.12

Nominal : 1.05

m.p. (°C (K)) : 240 (513)

b.p. (°C (K)) :

v.p. (mm Hg (Pa)) :

Brittle point (°C (K)) :

f.p. (°C (K)) :

Crystal data : rhombohedral, amorphous

a = 21.90

c = 6.63

R :

n : 1.59-1.60

Shore hardness :

5. CHEMICAL PROPERTIES

ΔH_f (kcal/mol (kJ/mol)) : +18.9 (+79.1)

Solubility (s-sol., sl-sl. sol., i-insol.) :
s – benzene, toluene

7. MECHANICAL PROPERTIES

Tensile strength (psi (kPa)):

Elongation (%) :

Sound velocity (km/s):	C_ℓ	C_s	C_b
(ρ = 1.06)	--	--	1.98

6. THERMAL PROPERTIES

λ : 2.51×10^{-4} cal/cm-sec-°C (0.105 W/m-K) at 273 K

CTE : α = 60-80 µm/m-K < T_β

β = 170-210 µm/m-K < T_g

= 510-600 µm/m-K > T_g

T_g (°F (K)) : 373 K

C_p (cal/g-°C (kJ/kg-K)) :
0.300 at 50°C (1.255 at 323 K)

10. ELECTRICAL PROPERTIES

ϵ :

2.49-2.55 (amorph., ρ = 1.05)

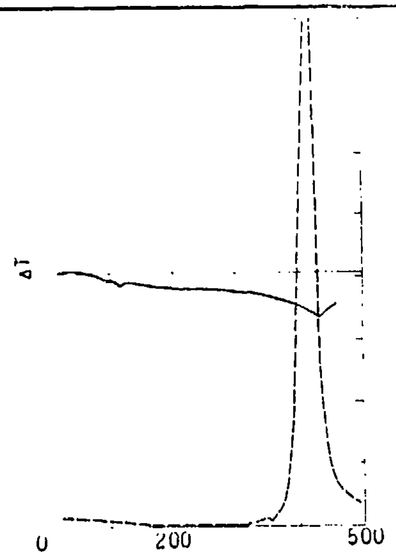
2.61 (cryst., ρ = 1.12)

11. TOXICITY

NOTES

3/81

Polystyrene

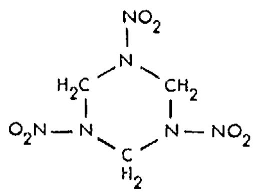


DTA (—) and pyrolysis (--) curves

EXPLOSIVE: HEXAHYDRO-1,3,5-TRINITRO-1,3,5-TRIAZINE

DESIGNATION: **RDX**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_3H_6N_6O_6$

MW: 222.1

Density (g/cm^3): TMD: 1.806

Nominal: —

m.p. (°C (K)): 205 (478) with decomp.

b.p. (°C (K)): —

v.p. (mm Hg (Pa)):

Crystal data:

I: orthorhombic (Pbca) II: unstable

a = 13.18
b = 11.57
c = 10.71

R: 43.7 (calc.), 41.4 (obs.)

n: see Table 4-3

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.62 (6.78)	1.48 (6.19)
Exp:	1.51 (6.32)	1.42 (5.94)

ΔH_f (kcal/mol (kJ/mol)): +14.71 (+61.55)

Solubility (s-sol., sl-sl. sol., i-insol.):
s—acetone, DMFA, DMSO, N-methylpyrrolidone
sl—ethanol, pyridine
i—benzene, carbon disulfide, carbon tetrachloride, chloroform, ethyl acetate, ethyl ether, water

6. THERMAL PROPERTIES

λ: 2.53×10^{-4} cal/cm-sec-°C (0.106 W/m-K)

CTE: α = 63.6 μm/m-K at 293 K
β = 191 μm/m-K at 293 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Exp.: 0.269 (1.126 at 298 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.02-0.025

1 g for 48 hr: 0.12-0.9

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 8.70 (ρ = 1.77)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.767)

Meas.: 338

Calc.: 348

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ = 1.80)

6 mm: —

19 mm: ~1.60

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.28	—
2.5 kg:	0.28	0.32

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):

NSWC-SSGT:		(7.90)	(ρ = 1.717)
LANL-SSGT:	190-220	(4.8-5.6)	(ρ = 1.735)
LANL-LSGT:	2.434	(61.82)	(ρ = 1.750)

10. ELECTRICAL PROPERTIES:

ϵ: 3.14 (ρ = 1.611)

11. TOXICITY

Low

RDX

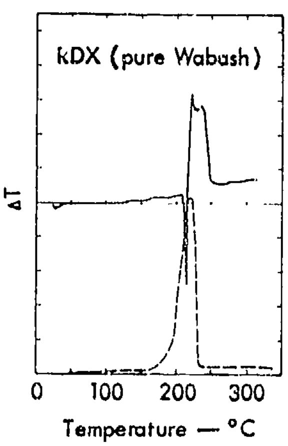
7. MECHANICAL PROPERTIES

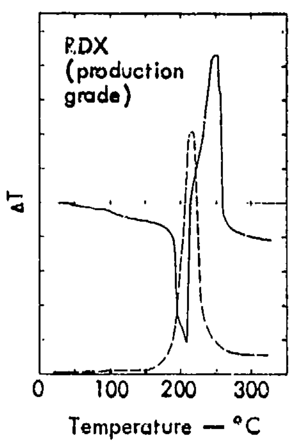
Sound velocity (km/s)	C_ℓ	C_s	C_b
(ρ = 1.80)	--	--	2.65

Initial modulus

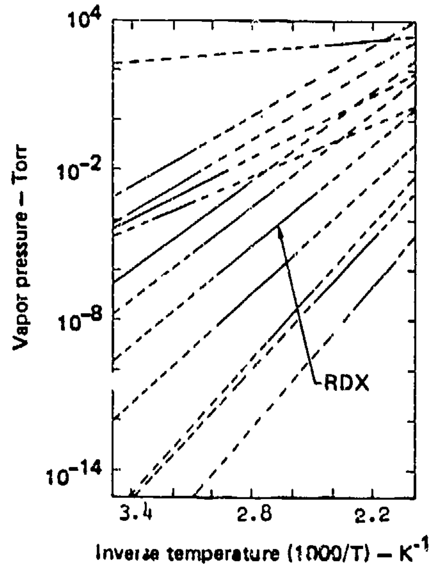
Creep

NOTES

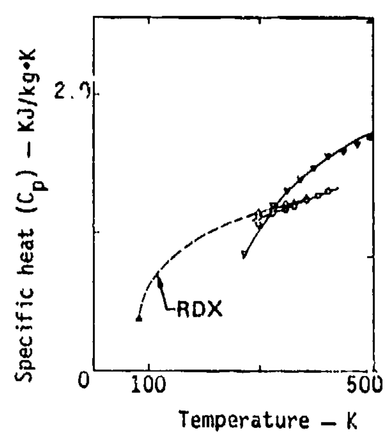




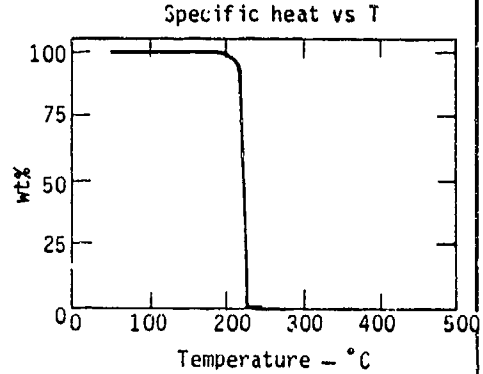
DTA (—) and pyrolysis (--) curves



Vapor pressure vs 1/T



Specific heat vs T



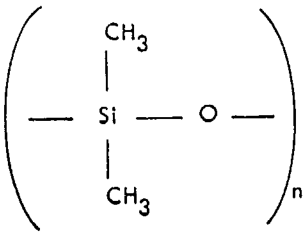
TGA curve

MATERIAL: SILICON RESIN (Binder)

DESIGNATION: **Sylgard**

SUPPLIER: Dow Corning

2. STRUCTURAL FORMULATION



4. PHYSICAL PROPERTIES

Physical state: liquid

Color: light straw

At. comp.: $(C_2H_6OSi)_n$

MW: $(74.16)_n$

Density (g/cm^3): TMD: 1.05 at 25°C (298 K)

Nominal:

m.p. (°C (K)):

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

Brittle point (°C (K)): <-70°C (<203 K)(cured)

f.p. (°C (K)):

Crystal data:

R:

n: 1.430 at 25°C (298 K)

Shore hardness: A 40-50 (cured)

5. CHEMICAL PROPERTIES

ΔH_f (kcal/mol (kJ/mol)): -24.9 (-104.18)

Solubility (s-sol., sl-sl. sol., i-insol.):

7. MECHANICAL PROPERTIES

Tensile strength (psi (kPa)):
800-1200 (55-83)

Elongation (%): 80-140

6. THERMAL PROPERTIES

λ: 3.5×10^{-4} cal/cm-sec-°C (0.146 W/m-K) (cured)

CTE: 180 μin./in.-°F at -65 to 165°F
(324 μm/m-K at 219-347 K)

T_g (°F (K)):

C_p (cal/g-°c (kJ/kg-K)): 0.34 at 25°C
(1.423 at 298 K)

10. ELECTRICAL PROPERTIES

ϵ: 2.77 (ρ = 1.05)

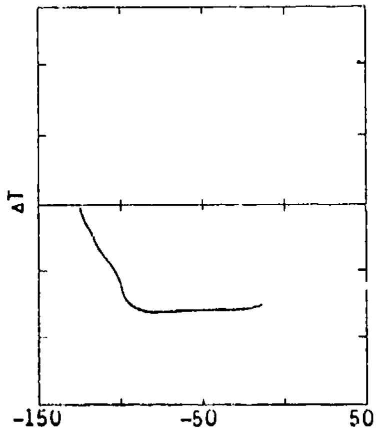
11. TOXICITY

NOTES

Replaces Q-93-022.

3/81

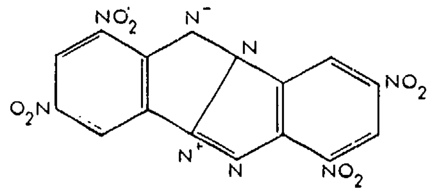
Sylgard



DTA curve

EXPLOSIVE: 2,4,8,10-TETRANITRO-5H-BENZOTRIAZOLO-[2,1-a]-BENZOTRIAZOL-6-IUM, HYDROXIDE, INNER SALT	DESIGNATION: **TACOT**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: red-orange

At. comp.: $C_{12}H_4N_8O_8$

MW: 388.2

Density (g/cm^3): TMD: 1.85

Nominal: 1.61

m.p. (°C (K)): dec. >380 (>653)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.41 (5.90)	1.35 (5.64)
Exp:	0.98 (4.10)	0.96 (4.02)

ΔH_f (kcal/mol (kJ/mol)): +110.5 (+462.3)

Solubility (s-sol., sl-sl. sol., i-insol.):
s—DMSO
sl—DMFA, nitric acid, pyridine
i—chloroform, ethanol, water

6. THERMAL PROPERTIES

λ: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.25 (ρ= 1.85)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.61)

Meas.: —

Calc.: 181

F_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
	—	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (ρ= 1.698)
NSWC-SSGT: (4.52)

10. ELECTRICAL PROPERTIES:

ϵ: —

11. TOXICITY

—

TACOT

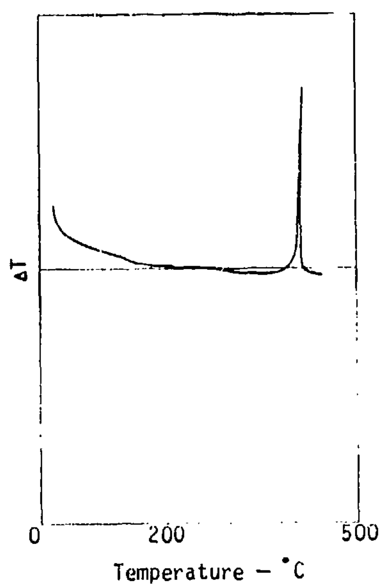
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envolope

NOTES

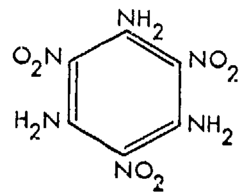


DTA curve

EXPLOSIVE: 2,4,6-TRINITRO-1,3,5-BENZENETRIAMINE

DESIGNATION: **TATB**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: bright yellow

At. comp.: $C_6H_6N_6O_6$

MW: 258.2

Density (g/cm^3): TMD: 1.938

Nominal: 1.88

m.p. (°C (K)): dec. >325 (>598); m.p. 452 (725)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): 3.2×10^{-3} at 175°C

(4.26×10^{-1} at 448 K)

Crystal data: triclinic ($P\bar{1}$)

a = 9.01	α = 108.6
b = 9.03	β = 91.8
c = 6.81	γ = 120

R: —

n: see Table 4-3

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.20 (5.02)	1.08 (4.52)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): -36.85 (-154.2)

Solubility (s-sol., sl-sl. sol., i-insol.):
s--sulfuric acid
i--acetone, benzene, carbon disulfide, carbon tetrachloride, chloroform, DMFA, DMSO, ethanol, ethyl acetate, ethyl ether, water

6. THERMAL PROPERTIES

λ: 12.8×10^{-4} cal/cm-sec-°C (0.536 W/m-K) at 311 K

CTE: α = 54 µm/m-K at 200 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): --

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/µsec (km/s)): 7.76 (ρ= 1.88)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.88)

Meas.: —

Calc.: 291

E_{cyl} ($(mm/\mu sec)^2/2$ (MJ/kg)): (ρ= 1.854)

6 mm: 0.874

19 mm: 1.079

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	>1.77	—
2.5 kg:	>3.20	>3.20

Susan test: Threshold velocity ~1000 m/s. Behaves like mock to 1000 m/s.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):

NSWC-SSGT:	(1.12)	(ρ = 1.887)
LANL-SSGT:	(0.13)	(ρ = 1.872)
LANL-LSGT:	(21.9)	(ρ = 1.870)
PX-GT:	(~5.3)	(ρ = 1.883)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

Low

TATB

7. MECHANICAL PROPERTIES

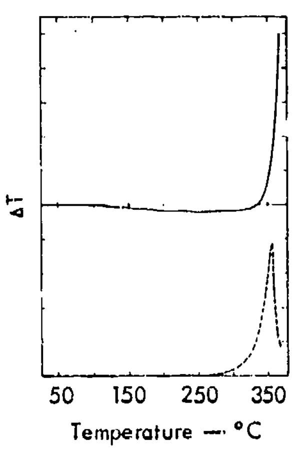
Sound velocity (km/s)	C_ℓ	C_s	C_b
(ρ = 1.868)	1.907	1.083	1.439

Initial modulus

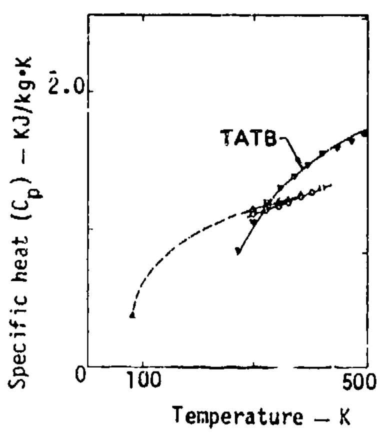
Creep

Failure envelope

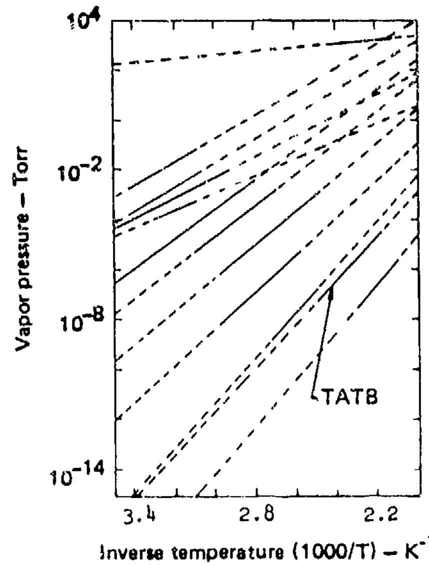
NOTES



DTA (—) and pyrolysis (--) curves



Specific heat vs T

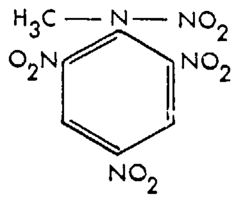


Vapor pressure vs 1/T

EXPLOSIVE: N-METHYL-N,2,4,6-TETRANITROBENZENAMINE

DESIGNATION: **Tetryl**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: yellow

At. comp.: $C_7H_5N_5O_8$

MW: 287.0

Density (g/cm^3): TMD: 1.73

Nominal: 1.71

m.p. (°C (K)): 130 (403)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: monoclinic ($P2_1/c$)

a = 14.13
b = 7.37
c = 10.61
β = 95.1

R: —

n: 1.606

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (*l*)	H_2O (g)
Calc:	1.51 (6.32)	1.45 (6.07)
Exp:	1.14 (4.77)	1.09 (4.56)

ΔH_f (kcal/mol (kJ/mol)): +4.67 (+19.5)

Solubility (s-sol., sl-sl. sol., i-insol.):
s--acetone, benzene, DMFA, ethyl acetate, nitric acid
sl--chloroform, ethanol, ethyl ether
i--carbon disulfide, carbon tetrachloride, water

6. THERMAL PROPERTIES

λ: 6.83×10^{-4} cal/cm-sec-°C (0.286 W/m-K)

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —
Exp. 0.252 at 25°C (1.054 at 298 K)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.036

1 g for 48 hr: 5.10

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.85 (ρ= 1.71)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.71)

Meas.: —

Calc.: 260

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ =)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.28	—
2.5 kg:	0.37	0.41

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)):

NSWC-SSGT:	(7.8)	(ρ = 1.687)
LANL-SSGT:	(3.84)	(ρ = 1.684)
LANL-LSGT:	2.386 (60.6)	(ρ = 1.666)

10. ELECTRICAL PROPERTIES:

ε: 2.059 (ρ = 0.9) 2.163 (ρ = 1.0)
2.728 (ρ = 1.4) 3.097 (ρ = 1.6)
2.905 (ρ = 1.5) 3.304 (ρ = 1.7)

11. TOXICITY

High

1/85

Tetryl

7. MECHANICAL PROPERTIES

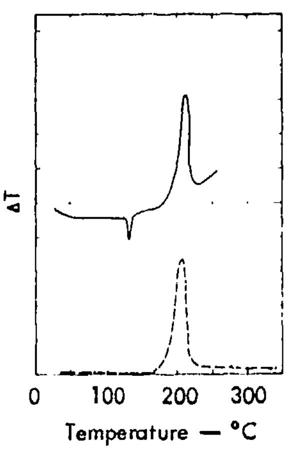
Sound velocity (km/s)	C_ℓ	C_s	C_b
(ρ = 1.68)	2.27	1.24	1.76

Initial modulus

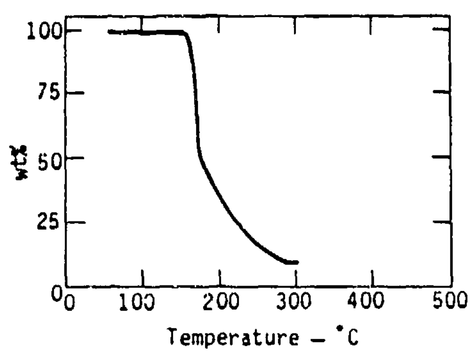
Creep

Failure envelope

NOTES



DTA (—) and pyrolysis (--) curves

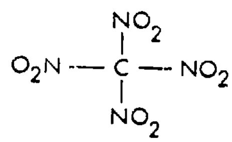


TGA curve

EXPLOSIVE: TETRANITROMETHANE

DESIGNATION: **TNM**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: liquid

Color: clear

At. comp.: $C_1N_4O_8$

MW: 196.0

Density (g/cm^3): TMD: 1.650 at 286 K

Nominal: —

m.p. (°C (K)): 14.2 (287)
b.p. (°C (K)): 125.7 (399)
v.p. (mm Hg (Pa)): 13 at 25°C (1733 at 298 K)

Crystal data: —

R: —

n: 1.4359

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	0.55 (2.30)	0.55 (2.30)
Exp:	—	—

ΔH_f (kcal/mol (kJ/mol)): +13.0 (+54.4)

Solubility (s-sol., sl-sl. sol., i-insol.):

s—benzene, ethanol, ethyl ether
sl—water

6. THERMAL PROPERTIES

λ: —

CTE: —

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: —

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 6.4 (ρ= 1.6)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.65)

Meas.: —

Calc.: 144

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm: —

19 mm: —

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
	—	—

Susan test: —

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): — (ρ=)

10. ELECTRICAL PROPERTIES:

ε: —

11. TOXICITY

Very high

TNM

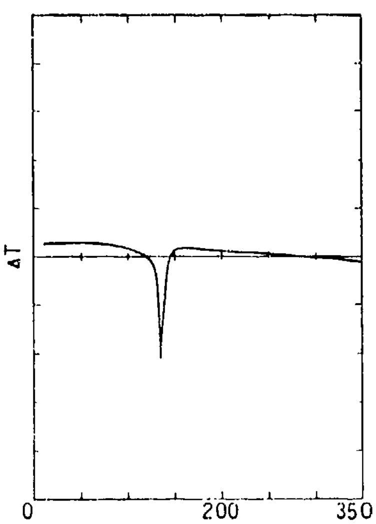
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

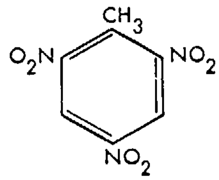
NOTES



DTA curve

EXPLOSIVE: 2-METHYL-1,3,5-TRINITROBENZENE	DESIGNATION: **TNT**

2. STRUCTURE OR FORMULATION



4. PHYSICAL PROPERTIES

Physical state: solid

Color: buff to brown

At. comp.: $C_7H_5N_3O_6$

MW: 227.1

Density (g/cm^3): TMD: 1.654

Nominal. 1.5-1.6 (cast)
1.63-1.64 (pressed)

m.p. (°C (K)): 80.9 (354)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): 0.106 at 100°C (14.13 at 373 K)

Crystal data: Monoclinic ($P2_1/c$) orthorhombic ($Pca2_1$)

Monoclinic ($P2_1/c$)	orthorhombic ($Pca2_1$)
a = 21.28	a = 15.01
b = 6.09	b = 6.11
c = 15.03	c = 20.02
β = 111	

R: 44.3 (calc.), 49.6 (obs.)

n: 1.6

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.41 (5.90)	1.29 (5.40)
Exp:	1.09 (4.56)	1.02 (4.27)

ΔH_f (kcal/mol (kJ/mol)): -16.0 (-66.9)

Solubility (s-sol., sl-sl. sol., i-insol.):
s — acetone, benzene, chloroform, DMFA, ethyl acetate, nitric acid, pyridine, sulfuric acid
sl — carbon disulfide, carbon tetrachloride, ethanol, ethyl ether; i — water

6. THERMAL PROPERTIES

λ: 6.22×10^{-4} cal/cm-sec-°C (0.260 W/m-K) at 291-318 K

CTE: α = 50 + 0.078T μm/m-K below m.p.
β ~ 180 at 293 K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)): —
Exp. 0.36 (1.51)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: 0.00-0.012

1 g for 48 hr: ~0.005

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 6.93 (ρ = 1.64)

P_{CJ} (kbar (10^{-1} GPa)): (ρ = 1.630)

Meas.: 210

Calc.: 223

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ = 1.630)

6 mm: 0.735

19 mm: 0.975

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg:	0.80	>1.77
2.5 kg:	1.48	~1.00

Susan test: Threshold velocity ~235 ft/sec (~72 m/s); very difficult to ignite accidentally, and has very low probability of buildup to violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
14 (0.24)	10.0 (3.05)	2

Gap test (mils (mm)):

NSWC-SSGT:	(3.96)	(ρ = 1.651)
LANL-SSGT:	(0.33)	(ρ = 1.633)
LANL-LSGT:	1.944 (49.4)	(ρ = 1.626)

10. ELECTRICAL PROPERTIES:

ε: 2.048 (ρ = 0.9) 2.131 (ρ = 1.0)
2.629 (ρ = 1.4)
2.795 (ρ = 1.5)
2.88 (ρ = 1.6)

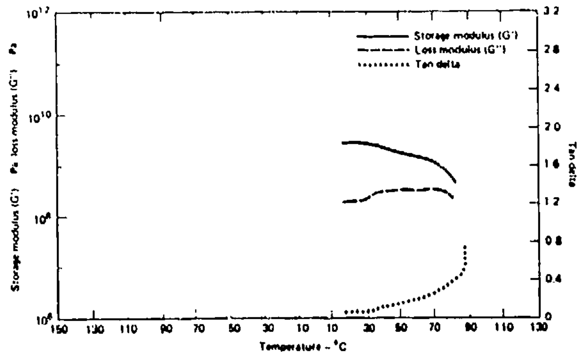
11. TOXICITY

Moderate

TNT

7. MECHANICAL PROPERTIES

Sound velocity (km/s):	C_ℓ	C_s	C_b
(ρ = 1.632)	2.58	1.35	2.08



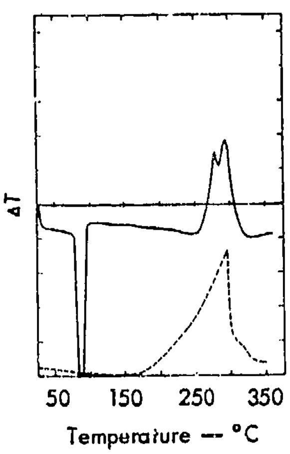
Complex shear moduli

Initial modulus

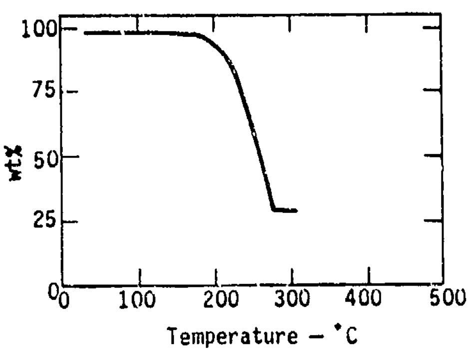
Creep

Failure envelope

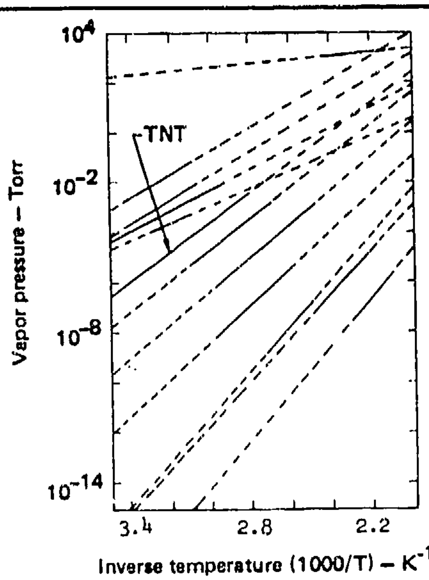
NOTES



DTA (·—) and pyrolysis (---) curves



TGA curve



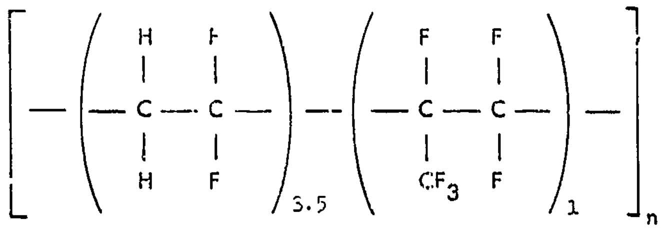
Vapor pressure vs 1/T

MATERIAL:
VINYLIDINE FLUORIDE/HEXAFLUOROPROPYLENE COPOLYMER (Binder)

DESIGNATION : **Viton A**

SUPPLIER : DuPont

2. STRUCTURAL FORMULATION



4. PHYSICAL PROPERTIES

Physical state : rubbery solid

Color : white

At. comp. : $(C_5H_{3.5}F_{6.5})_n$

MW : $(187.08)_n$

Density (g/cm^3) : TMD :

Nominal : 1.8-1.9

m.p. (°C (K)) :

b.p. (°C (K)) :

v.p. (mm Hg (Pa)) :

Brittle point (°C (K)) :

f.p. (°C (K)) :

Crystal data :

R :

n :

Shore hardness : A 40-60 (71 cured)

5. CHEMICAL PROPERTIES

ΔH_f (kcal/mol (kJ/mol)) : -332.7 (-1392)

Solubility (s-sol., sl-sl. sol., i-insol.) :

s – acetone, MEK, MIBK, n-butyl acetate, THF

7. MECHANICAL PROPERTIES

Tensile strength (psi (kPa)):

Elongation (%) :

6. THERMAL PROPERTIES

λ : 5.4×10^{-4} cal/cm-sec-°C (0.226 W/m-K)

CTE : α = 65.0 μin./in.-°F at <-6°F (117 μm/m-K at <252 K)

α = 145.2 μin./in.-°F at -6 to 165°F (254.8 μm/m-K at 252-347 K)

β = ~450 μm/m-K at <253 K
= 728 μm/m-K at 253-343 K

T_g (°F (K)) : -27°C (246 K)

C_p (cal/g-°C (kJ/kg-K)) : 0.35 (1.464)

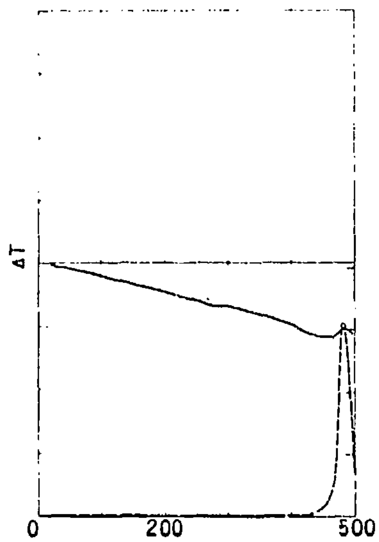
10. ELECTRICAL PROPERTIES

ϵ : 10.5 (ρ = 1.8-1.86)

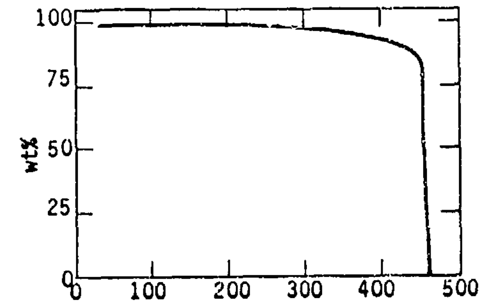
11. TOXICITY

NOTES

Viton A



Temperature — °C
DTA (—) and pyrolysis (--) curves



Temperature — °C
TGA curve

EXPLOSIVE: XTX-8003

DESIGNATION: **XTX-8003**

2. STRUCTURE OR FORMULATION

	wt%
PETN	80
Silicone rubber	20

4. PHYSICAL PROPERTIES

Physical state: putty curable to rubbery solid

Color: white

At. comp.: $C_{1.80}H_{3.64}N_{1.01}O_{3.31}Si_{0.27}$

MW:

Density (g/cm^3): TMD: 1.556

Nominal: ≈1.53

m.p. (°C (K)): 129-135 (402-408)

b.p. (°C (K)): —

v.p. (mm Hg (Pa)): —

Crystal data: —

R: —

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.88 (7.89)	1.69 (7.07)
Exp:	1.16 (4.85)	1.05 (4.39)

ΔH_f (kcal/mol (kJ/mol)): -39 (-163)

Solubility (s-sol., sl-sl. sol., i-insol.): —

6. THERMAL PROPERTIES

λ: 3.42 × 10^{-4} cal/cm-sec-°C (0.143 W/m-K)

CTE:

α = 68.8 μin./in.-°F at -22 to 158°F (123.8 μm/m-K at 243-343 K)

α = 77 μin./in.-°F at 75 to 150°F (139 μm/m-K at 297-339 K)

β = 413.7 μm/m-K at 219-296 K)

6. THERMAL PROPERTIES (continued)

T_g (°F (K)): —

C_p (cal/g-°C (kJ/kg-K)):
Est.: 0.27 (1.13)

Thermal stability (cm^3 of gas evolved at 120 °C (393 K)):

0.25 g for 22 hr: < 0.02 at 100°C (373 K)

1 g for 48 hr: —

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.30 (ρ= ≈1.53)

P_{CJ} (kbar (10^{-1} GPa)): (ρ= 1.546)

Meas.: 170

Calc.: 210

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ= 1.554)

6 mm: 0.710

19 mm: 0.950

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
5 kg: Cured:	0.21	—
5 kg: Uncured:	0.25	—
2.5 kg:	0.31	0.42

Susan test: Threshold velocity ~160 ft/sec (~49 m/s); has very small probability of buildup to violent reaction.

Skid test:

Impact angle (deg (rad))	Drop ht. (ft (m))	Event
—	—	

Gap test (mils (mm)): (ρ= 1.53)
LANL-SSGT: Cured: 130-160 (3.3-4.1)
LANL-SSGT: Uncured: 160-190 (4.1-4.8)

10. ELECTRICAL PROPERTIES:

ε : —

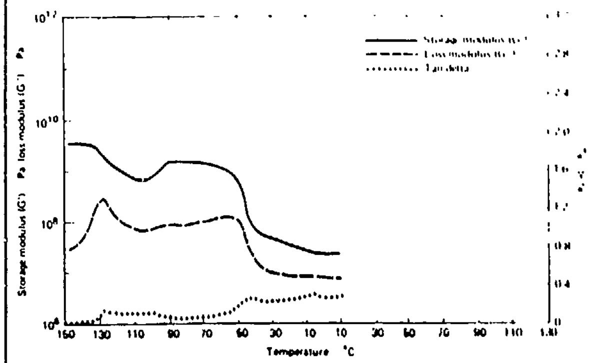
11. TOXICITY

—

3/81

7. MECHANICAL PROPERTIES

Initial modulus

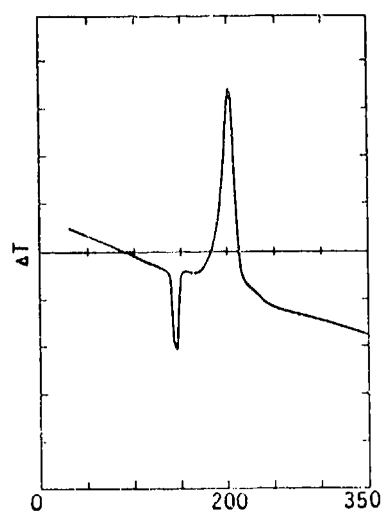


Complex shear moduli

Creep

Failure envelope

NOTES



DTA curve

EXPLOSIVE: XTX-8004

DESIGNATION: **XTX-8004**

2. STRUCTURE OR FORMULATION

	wt%
RDX	80
Sylgard 182	20

4. PHYSICAL PROPERTIES

Physical state: solid

Color: white

At. comp.: $C_{1.62}H_{3.78}N_{2.16}O_{2.43}Si_{0.27}$

MW:

Density (g/cm^3): TMD: 1.579

Nominal: ≈1.55

m.p. (°C (K)): 200 with dec.

b.p. (°C (K)):

v.p. (mm Hg (Pa)):

hygroscopiaty

hardness: S55

Crystal data:

R:

5. CHEMICAL PROPERTIES

ΔH_{det} (kcal/g (MJ/kg)):	H_2O (ℓ)	H_2O (g)
Calc:	1.87 (7.82)	1.67 (6.99)
Exp:		

ΔH_f (kcal/mol (kJ/mol)): -1.42 (-5.94)

Solubility (s-sol., sl-sl. sol., i-insol.):

s--acetone, DMFA, DMSO, N-methylpyrrolidone

sl--ethanol, pyridine

i--benzene, carbon disulfide, carbon tetrachloride, chloroform, ethyl acetate, ethyl ether, water

6. THERMAL PROPERTIES

λ: 3.42×10^{-4} cal/cm-sec-°C (0.143 W/m-K) at 313 K

CTE: α = 231 μm/m-K

6. THERMAL PROPERTIES (continued)

T_g (°F (K)):

C_p (cal/g-°C (kJ/kg-K)):

Thermal stability (cm^3 of gas evolved at 120 °C (393 K):

0.25 g for 22 hr: ~0.06

1 g for 48 hr:

8. DETONATION PROPERTIES

D (mm/μsec (km/s)): 7.22 (ρ= ~1.55)

P_{CJ} (kbar (10^{-1} GPa)): (ρ=)

Meas.:

Calc.:

E_{cyl} ((mm/μsec)^2/2 (MJ/kg)): (ρ=)

6 mm:

19 mm:

9. SENSITIVITY

H_{50} (m):	12 tool	12B tool
2.5 kg:	0.65-0.70	1.41-1.70

Susan test:

Skid test:

Impact angle (deg (rad)) Drop ht. (ft (m)) Event

Gap test (mils (mm)): (ρ=)

LANL-SSGT: (1.96) (ρ = 1.58)

10. ELECTRICAL PROPERTIES:

ε:

11. TOXICITY

Low

XTX-8004

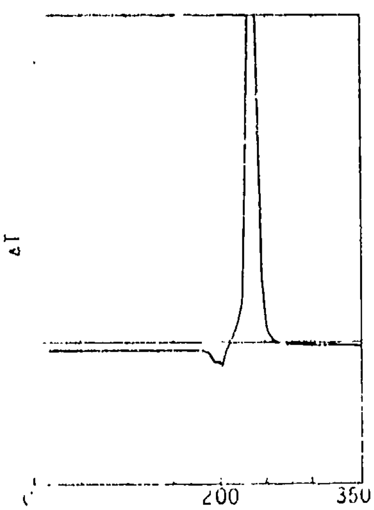
7. MECHANICAL PROPERTIES

Initial modulus

Creep

Failure envelope

NOTES



Temperature — °C
DTA curve

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